Managing Interstation Interference

Coaxial Stubs and Filters

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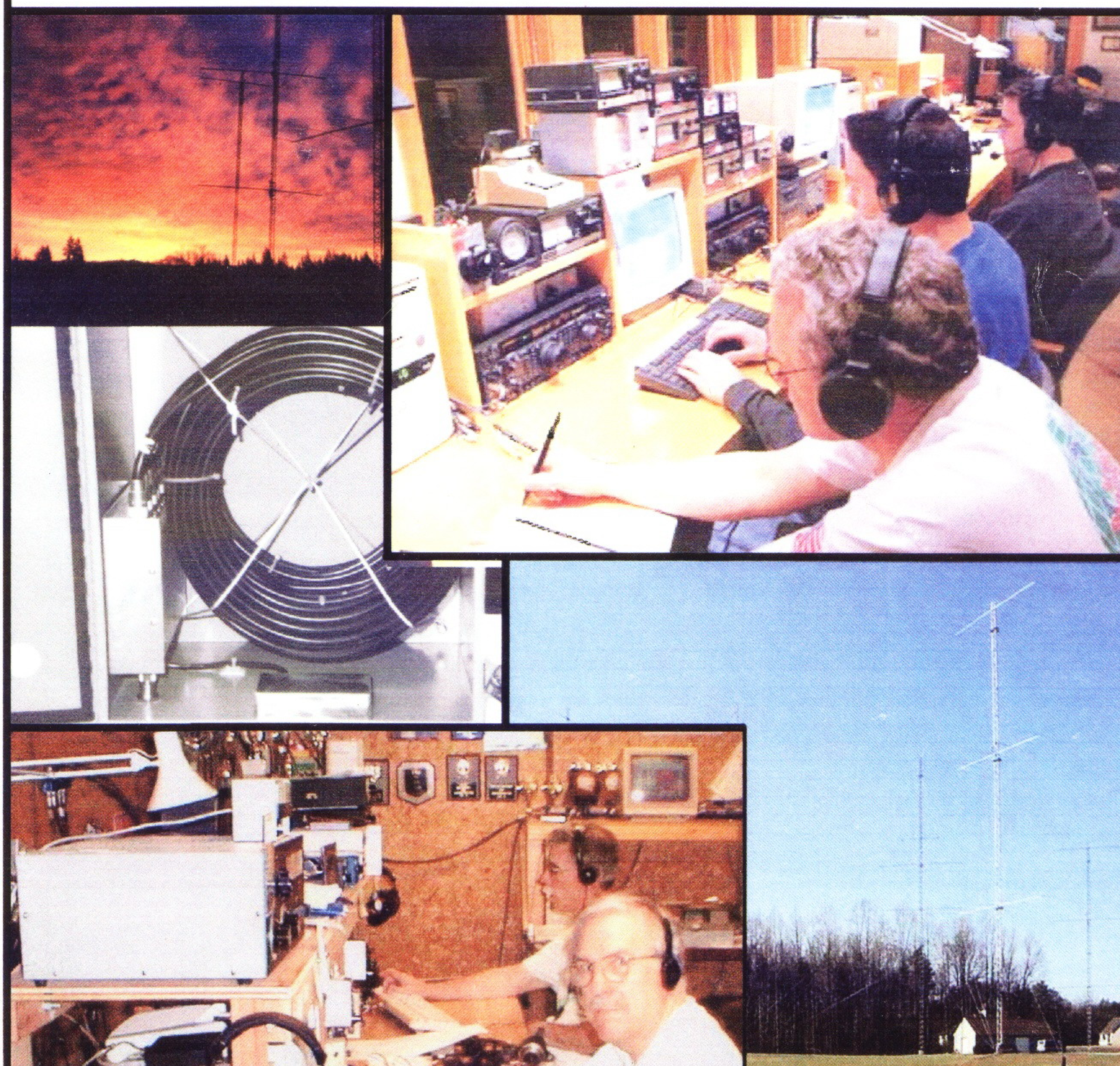

Cover photos

Upper left. Daybreak at W7RM.
Upper right. N3BB. Operators are N3BB, W5RQA and KI5DR.
Center left. Bandswitching stub assembly built by the author.
Lower left. Operating position at N3RS. W8FJ and N3RD.
Lower right. Some of the K4JA antennas.

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1.0 DEFINING THE PROBLEM

1.1 Basics and Terminology

Whenever two or more transceivers are used in close proximity there is some level of interference involved. This level can vary from practically no problem to actually burning up components in the receiving radio. The purpose of this book is to identify and quantify the various parameters that create the interference and to show methods that will reduce or eliminate it.

To understand the problem it is necessary to learn about the imperfections in modern transmitters and receivers. Transmitters produce substantial output at multiples of the operating frequency. There are noise sources in them that will be radiated along with the desired signal. Receivers can tolerate signals only below certain levels that will create nonlinearities which make reception difficult or impossible, or that will physically damage them.

It's also necessary to understand something about the use of dB, dBm, dBm/Hz, etc., in order to discuss the problem intelligently. This is where we begin.

1.1.1 Understanding the various forms of dB that the RF engineer uses

Using dB allows us to talk about very large differences in power or Voltage levels with numbers that are easy to comprehend. For example: the maximum power output of a legal transmitter in the USA is 1500 Watts and the noise floor of a modern receiver is 0.04 microVolts. The received power at this Voltage level into 50 ohms is 0.00000000000000003 Watts or 3×10^{-17} Watts. These numbers are not easy to deal with. RF engineers refer to power levels as dB above or below 1 milliWatt in a 50 ohm system and call the result dBm. Thus, 1 milliWatt is 0 dBm. If we convert the above power levels to dBm, we obtain +62 dBm for transmitter output and –135 dBm for receiver noise floor. The equations:

1500 Watts in dBm = 10 log (1500 / .001) = +62

$3\text{x}10^{-17}$ Watts in dBm = 10 log (3×10^{-17} / .001) = -135

For narrow band signals such as CW, these numbers are easy to calculate from the amount of power read on a Wattmeter. For example:

How many dBm is a 100 Watt transmitter producing?

100 Watts in dBm = 10 log (100/0.001) = 10 log(100,000) = 10 x 5 = +50dBm

When considering wideband noise an additional factor must be added. The level of noise introduced into a receiver output will depend upon the noise power and the bandwidth of the receiver. The noise may exist over a large bandwidth, but we are interested only in the noise power within our receiver bandwidth. By taking a standard very narrow slice of noise, we can obtain a number that is useful in predicting interference effects. The common bandwidth reference is 1 Hz. Noise power then is defined as noise density in terms of dBm/Hz. If we measure –50 dBm of noise out of a receiver that has 500 Hz bandwidth the power in dBm/Hz would be:

Noise power = -50 dBm – 10 log 500 = -50 dBm – 27 dB = -77dBm/Hz

Where the –27 dB is due to the ratio of bandwidths from 1 Hz to 500 Hz.

This measurement can be made with a true rms AC meter and a signal generator used for a reference. The rms meter reading on the noise source is set to a convenient value on the scale by adjusting the radio volume control. The signal generator is then substituted for the receiver input source and is set to the received frequency. The generator output is then adjusted for the same audio output on the rms meter. The noise power is then equal to the signal generator output power.

Another form commonly used is dBC, where C represents carrier. A number expressed in dBC is dB related to the carrier. Sidebands are generally expressed in dBC. Noise around a transmitted carrier would also be expressed in dBC.

1.2 Power Levels in the Amateur Station Transmitter

Even the best transmitters produce undesired products along with a main signal. These products can produce excessive interference in other radios that are being used nearby unless steps are taken to reduce them. Harmonics occur at integer multiples of the transmitted frequency. The 2nd and 3rd harmonics are usually the worst. For example, a 7 MHz transmitter will produce harmonic signals at 14 and 21 MHz with sufficient energy to cause interference while trying to listen on those bands. Two forms of random noise are also generated in a transmitter. These are phase noise and wide band transmitted noise, and are described below.

1.2.1 Harmonics

Transmitters produce harmonics, which can cause interference to receivers monitoring other amateur bands. The FCC regulations require these harmonics to be more than 40 dB down from the transmitted carrier or –40 dBC. When full legal power is being used, harmonics can be radiated at substantial power levels. Forty dB below 1500 Watts is 150 milliWatts or +22 dBm. These numbers can be taken as the worst case. Amplifiers with pi-L output networks may have harmonic levels considerably below –40 dBC.

1.2.2 Phase Noise

The frequency generating portion of a transmitter contains one or more oscillators, usually part of a frequency synthesizer. The solid state devices used to produce the oscillators are not noise free, so some random noise is present in the device currents. This noise modulates the generated waveform and creates small amounts of phase shift. These phase perturbations can be seen on a spectrum analyzer as a broadening of the generated waveform, or noise sidebands. These noise sidebands are called phase noise. The sideband level is generally highest close to the transmitted frequency. Further from the carrier frequency the noise is reduced until at some offset it reaches a plateau called the noise floor. Modern radios have a phase noise floor of about –140 dBm/Hz. *(See note 1.)* At an offset of 10 kHz it's about –130 and at 2 kHz offset it's about –115 to –120 dBm/Hz. The closer to the actual carrier that we tune, the stronger the phase noise becomes. This noise is present only when the transmitter is actually sending. The synthesizer is used in both transmitting and receiving, so phase noise also a receiving problem.

Note 1. To add realism to the calculations which follow, many of the radio characteristics listed have been taken from laboratory measurements of the FT-1000MP Mark V, performed by the ARRL. The author, on his FT-1000MP, has measured some of the numbers that were not measured by the ARRL.

1.2.3 Wide Band Noise

Solid-state transmitters use wideband amplifiers from the last mixer through the power amplifier at the 100 Watt level. The low level amplifiers in this chain have some internal noise, as does any real amplifier. This noise is amplified up to the power amplifier output. This amplified wide band noise will be present when the transmitter is activated, even before the carrier is turned on. The power amplifier is usually followed by a low pass filter that helps remove harmonics and also reduces the noise output for bands above the band in use.

As an example, assume a clean, noise free signal is heterodyned to the operating frequency by a noise free injection source. The typical output level of the mixer might be –10 dBm. The gain required to produce 100 Watts out of a transceiver would be 60 dB. Let's assume that the amplifier producing the gain has a noise figure of 4 dB. The input noise of such an amplifier is

$$-174 \text{ dBm/Hz} + 4 \text{ dB} = -170 \text{ dBm/Hz}.$$

Where –174 dBm/Hz is the noise in a 50 ohm resistor at 300 degrees Kelvin.

At the transceiver output this becomes –110 dBm/Hz. This level will increase by 27 dB for a receiver bandwidth of 500 Hz. Now the noise level becomes –83 dBm and related to the 100 Watt carrier power it is

$$-83-(+50) = -133 \text{ dBC}.$$

1.3 Maximum Receiver Levels

If a large enough signal is presented at a receiver input, damage to internal components will result. There are limits to how large a signal can be inputted to a receiver before it refuses to allow simultaneous reception of normal signals. Transmitter harmonics and noise can interfere with reception if their levels are high enough. Let's examine these various problem areas and assign specific levels below which normal reception can take place.

1.3.1 Receiver Damage

Examining the components that make up receiver input circuits will show what power levels are safe. Input attenuators commonly use resistors rated at 0.1 Watt. Switching diodes used to select input filters are usually rated at 0.2 Watts. To apply a safety factor of 2 to the resistor ratings would result in 0.05 Watts, or 50 milliWatts, or +17 dBm, being the maximum safe power. This is very safe, because it is highly unlikely that any one component will absorb most or all of the received power at the antenna input of the radio. The worst case would be in the attenuator resistors when the attenuation is set at maximum. Receiving under these signal conditions is impossible.

1.3.2 Receiver Blocking

When high level signals are applied to a receiver input there is a level, somewhat lower than the damage point, which disables or blocks reception. This level is a function of receiver design and varies depending upon the manufacturer and model. A top of the line modern receiver has a blocking level around +5 dBm for a signal offset of 50 kHz and 0 dBm for 20 kHz spacing. Receiving is useless, but no damage results.

1.3.3 Intermodulation Distortion

Intermodulation occurs when mixing action takes place between two or more signals to create new signals. Usually these are third order products of the type 2F1 - F2 and 2F2 – F1. For example: F1 at 7020 mixes with F2 at 7030 to form intermod products at 7040 and 7010. The level at which this happens in a modern radio is about –35 dBm. This is only 4 milliVolts and would read just under S9 +40 on an S meter. Receiving is possible with lots of interference from cross products.

1.3.4 Noise Floor

All transistors and integrated circuits used in the manufacture of receiver amplifiers and mixers have internal noise sources. This internal noise creates a limit, or floor, in signal level that can be received. The typical noise floor in today's radios is about –135 dBm.

1.4 The Power Level Chart

Figure 1 shows the various power levels of importance for analyzing interference problems in the amateur station. The dBm scale from +70 to –150 represents power levels from above maximum legal to below the best receiver sensitivity. Along the right side of the scale various important power levels are indicated. By taking the difference between two dBm levels of interest, the isolation in dB can be determined. For example: to reduce the +62 dBm transmitter output to that level which will not damage a receiver, 45 dB of isolation is required. To reduce the transmitted level to 10 dB below S9 that will minimize interference, 147 dB of isolation is needed. We will look into the various methods for obtaining isolation in later sections.

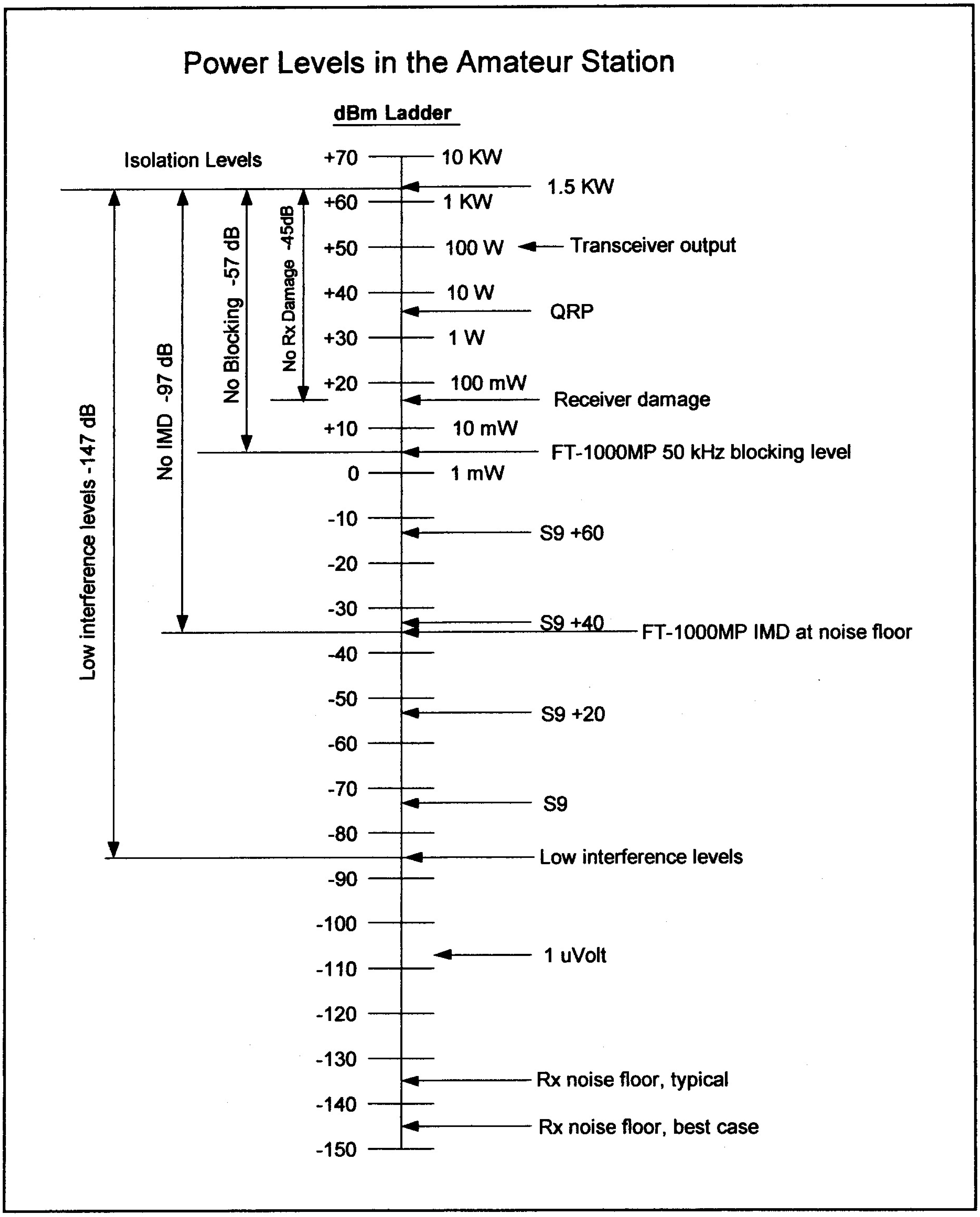


Figure 1 The dBm ladder.

2.0 FACTORS AFFECTING ISOLATION BETWEEN RADIOS

2.1 Basics

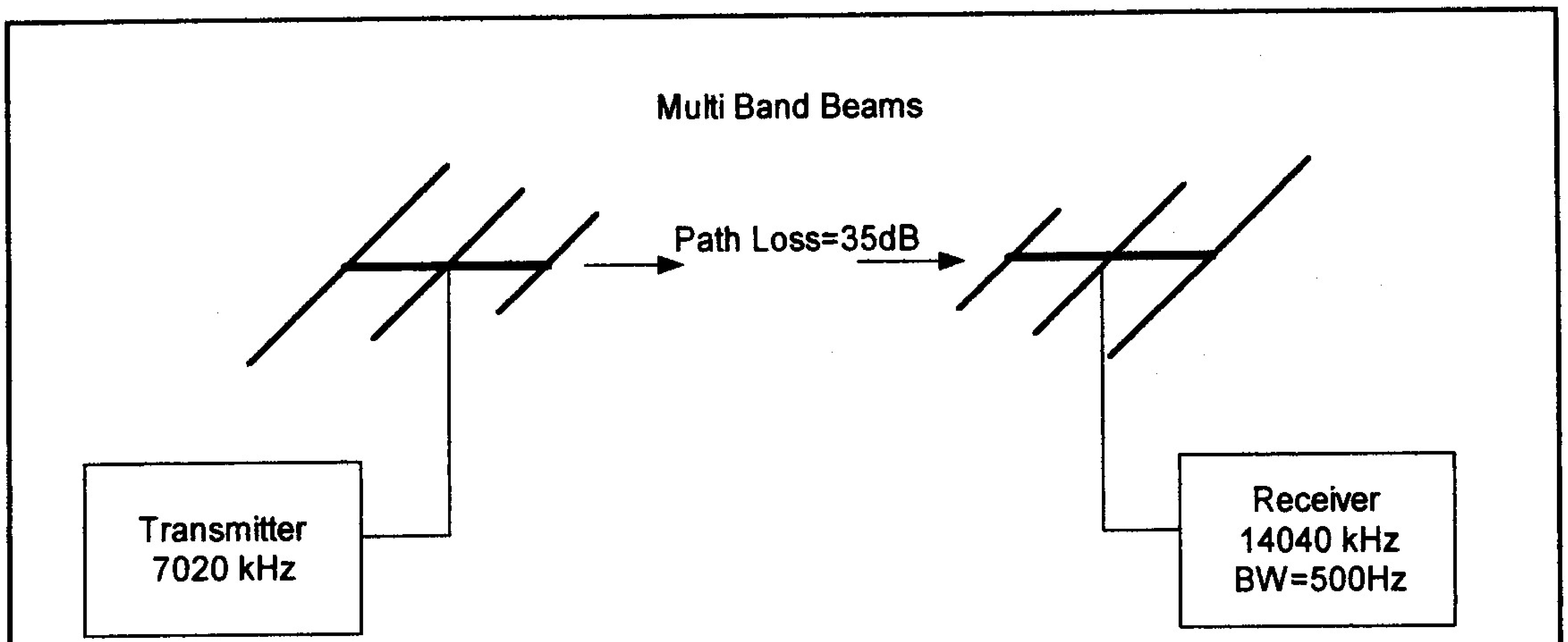
Several factors combine to determine how much power is presented to a receiver operated near a transmitter:

Antenna gain and spacing
Transmitter power output
Antenna orientation and polarization
Receiver antenna efficiency at the transmitted frequency

Obviously, more spacing between antennas will reduce the power picked up by the receiving antenna. Also, reducing the transmit power will reduce the interfering power at the receiver. If antennas are rotary, they may be oriented in such a manner that coupling is minimum. This usually occurs when the antenna ends are pointed at one another. Using cross-polarized antennas can also reduce coupling. Some stations with multiple transmitters and Yagi antennas use vertical antennas for spotting purposes. Using monoband antennas will reduce coupling due to the lower efficiency of Yagis when receiving off frequency signals. Multiband antennas are not the best choice when trying to isolate a receiver from a nearby transmitter.

2.2 Typical Numbers.

Figure 2 shows a two radio configuration using multiband antennas. One radio is transmitting at 1500 Watts on 40 meters and the second is receiving on 20 meters. The path loss between the antennas is 35 dB. The Tables show the levels of the various transmitted components. The receiver is using a 500 Hz bandwidth filter and we are assuming the antenna efficiency is the same on both bands.



Power Out	+62dBm
2nd Harmonic	+22dBm
3rd Harmonic	+12dBm
Phase Noise (Far from carrier)	-140dBC/Hz
Wide Band Noise (7MHz and below)	-110dBm/Hz

Power In	+27dBm
2nd Harmonic	-13dBm
3rd Harmonic	-23dBm
Phase Noise	-86dBm
Wide Band Noise	-118dBm

Figure 2 Transmit and receive levels in a typical 2 radio station.

The 7020 kHz carrier power radiated is +62 dBm and the receiver gets +27 dBm after the 35 dB path loss. From the chart in Figure 1 we see that +27 dBm exceeds the damage level we have set for the receiver. To make it safe, we need an additional 10 dB of isolation.

The second harmonic comes in at –13 dBm which exceeds the IMD creating level by 22 dB. The third harmonic comes in at –23 dBm, also exceeding the IMD level.

The phase noise (-86 dBm) and wideband noise (-118 dBm) each exceed the receiver noise floor by a considerable amount. Let's see how we got those numbers:

Transmitted phase noise = -140 dBC/Hz (measured value)
Transmitted power carrier level = +62 dBm
Transmitted phase noise power density = +62 dBm –140dBC/Hz = -78 dBm/Hz
Received phase noise power density = -78 dBm/Hz –35 dB = -113 dBm/Hz
Received phase noise power in 500 Hz band = -113 dBm/Hz +27 dB = -86 dBm

Transmitted wideband noise density = -110 dBm/Hz (measured value)
Received wideband noise density = -110 dBm/Hz -35 dB = -145 dBm/Hz
Received wideband noise power in 500 Hz band = -145 dBm/Hz + 27 dB = -118 dBm

Each of these noise factors will cause considerable interference to a radio with a −135 dBm noise floor.

So, in the example shown, all four of the transmitted parameters must be reduced in order to successfully operate the second receiver.

2.3 Antenna Isolation Measurements

Now that we have established some transmitted parameters and some receiver requirements for various levels of operation, we can look at the isolation measurements taken under real station conditions. At W2VJN there are two towers with a variety of antennas on each. Isolation measurements were made with a lab quality RF Voltmeter. The station transmitter was used with a Bird Wattmeter as the signal source. First we will look at a simple installation.

2.3.1 Small Tower with a Tribander and Wires.

Let's look at a small tower setup with a tribander and some wires. Figure 3 shows the antenna configuration.

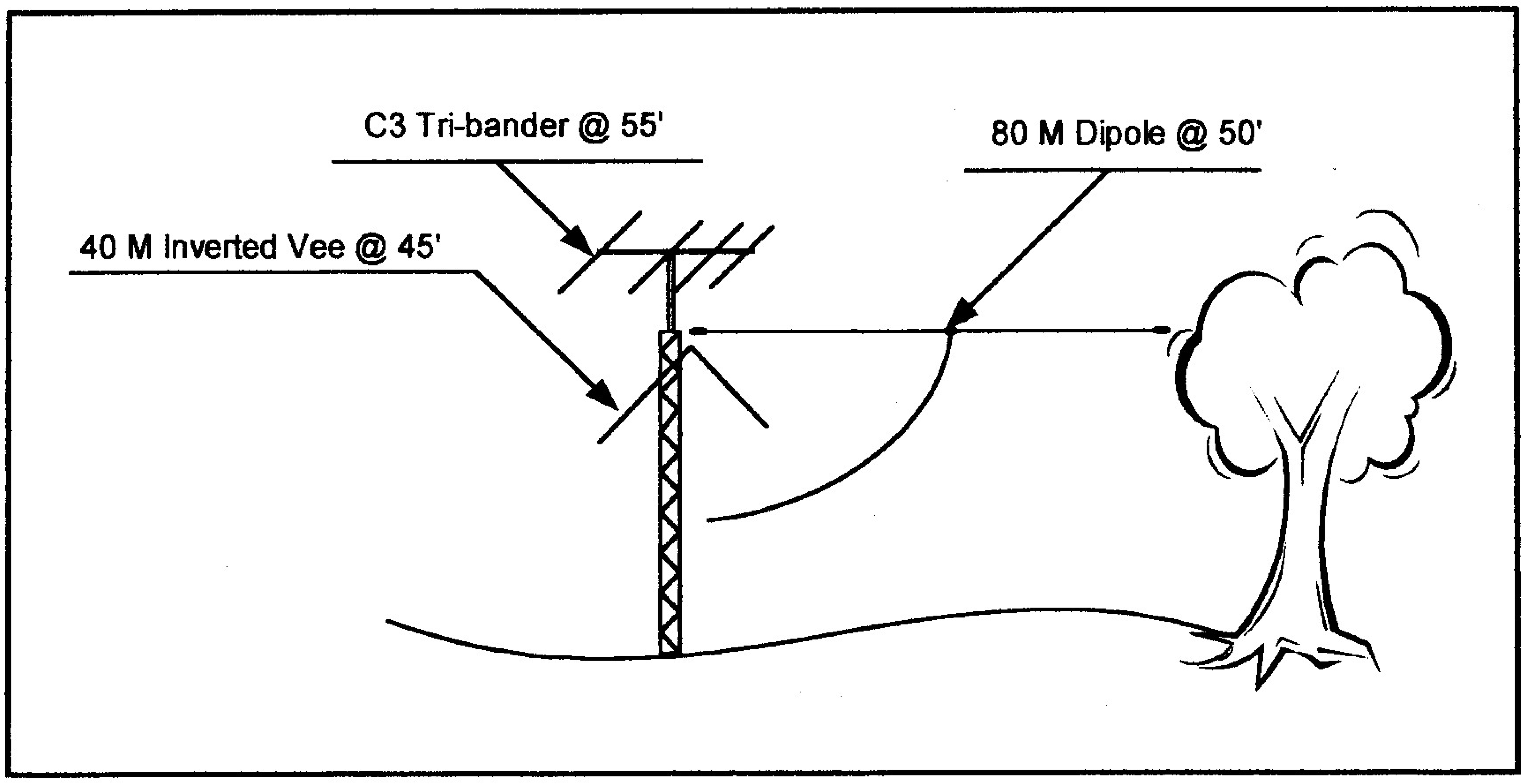


Figure 3 The small tower.

The tower is a 50 foot crank up. On top is a C3 tribander on a 5' mast. A 40 meter inverted vee is supported below the top of the tower at 45'. An 80 meter dipole runs from the tower top to a tree. The tribander is aligned with the 40 meter vee and is at right angles to the 80 meter dipole for the following measurements.

Table 1. Isolation between the tribander and wires

TX Band	10	15	20	40	80
RX Band					
10	-	-	-	-35	-32
15	-	-	-	-35	-32
20	-	-	-	-35	-32
40	-36	-23	-30	-	-34
80	-36	-40	-38	-27	-

Table 1 indicates the possible combinations of one antenna transmitting and a second receiving. The top line is the transmitting frequency and the left side column is the receiving frequency. The numbers refer to the isolation or attenuation from the transmitter fundamental frequency to the receiver input. The tribander is used on 20, 15 and 10 meters while the 40 and 80 meter dipoles are used on their respective bands. Looking at the first data row, –35 and –32 under 40 and 80 indicates the dB isolation between the 40 and 80 meter dipoles and the tribander. That is, when transmitting on 40 meters with the inverted vee, the tribander will pick up 40 meter energy, which is 35 dB down from the radiated power. Looking at the 40 meter RX row we see that transmitting into the tribander will inject 15 meter RF into the 40 meter antenna, which is 23 dB down from the radiated power, etc.

The value of 23 dB in the example is the worst case isolation between any combinations of antennas, so let's see what level of power will get to the receiver. If the transmitter is putting out 1500 Watts, then 23 dB isolation will inject 7.5 Watts into the second receiver if no precautions are taken. This is sure to cause extensive damage. Using dBm, 1500 Watts is about +62 dBm, and subtracting 23 dB gives +39 dBm. From the dBm ladder in Figure 1 we can see that we need about 22 dB additional isolation to prevent receiver damage. Even with 150 Watt transmitters we will need 12 dB additional isolation to prevent receiver damage. So running low power does not guarantee safety. *Only QRP levels would be safe with no additional precautions.*

Since these numbers are measured under specific conditions at one location, an additional safety factor should be added for unknowns and variations in antennas. Ten dB would not be too extravagant.

2.3.2 *A Larger Tower with Many Antennas*

Figure 4 shows an example of Yagis on a 150 foot tower.

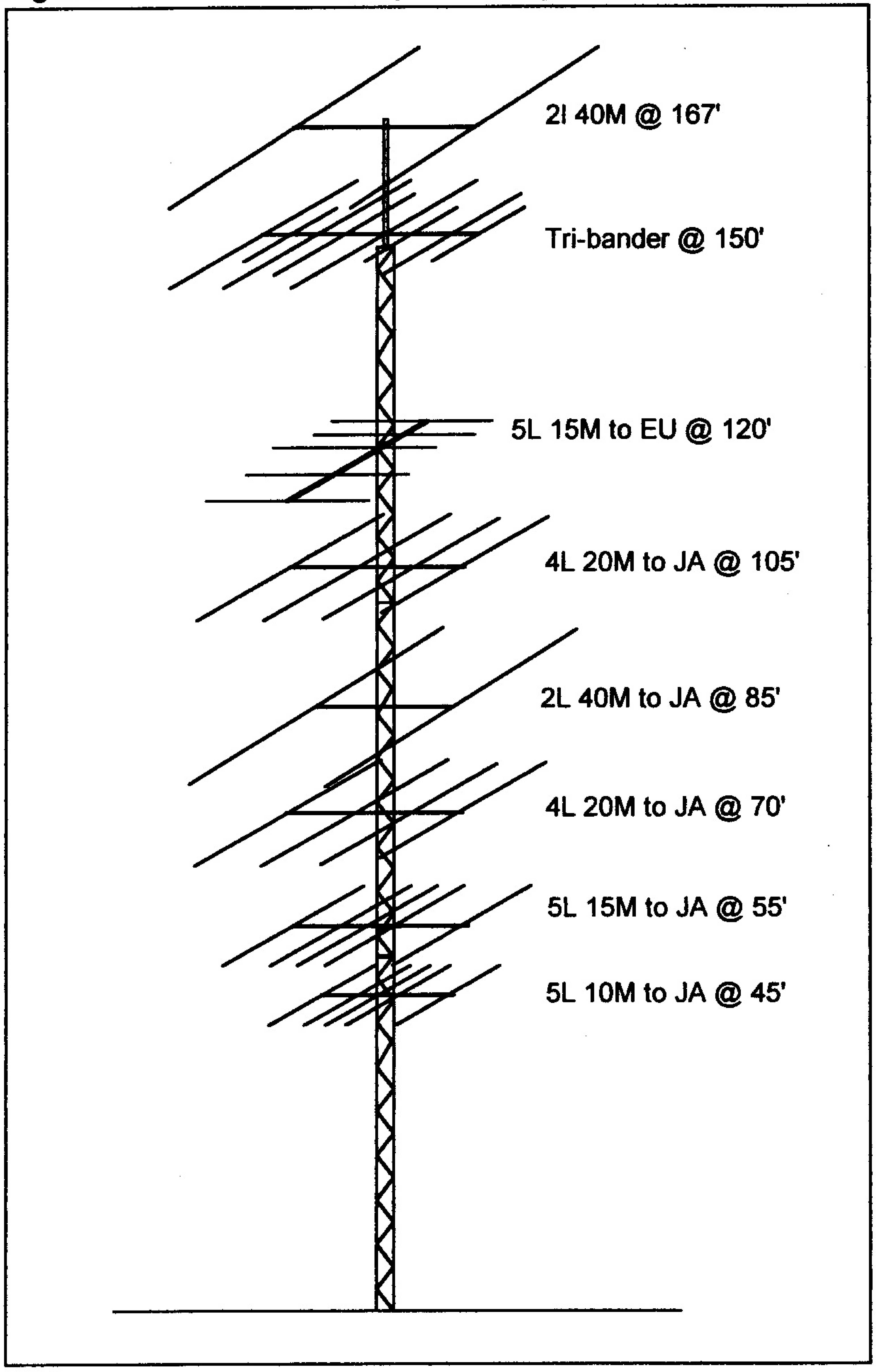


Figure 4 The large tower.

Rotating on top are a 2 element 40 and a large tribander. They are spaced at 17 feet apart. There are 6 Yagis side mounted below the top of the tower. All except the upper 5 element 15 meter beam are fixed on JA. The upper 15 is pointed at Europe. Table 2 shows isolation measurements made between the tribander and the other antennas. The tribander was the transmitting antenna and the power coupled into the various antennas was measured. In each case the tribander was rotated until maximum coupled power was noted.

Table 2 Isolation in dB with tri-bander transmitting.

Tx	20	15	10
Rx			
40R	-49	-35	-43
40JA	-68	-71	-67
20Stk	-62	-56	-64
15EU	-55	-47	-64
15JA	-59	-67	-70
10JA	-75	-72	-53

The minimum isolation occurrs between the tribander transmitting on 15 meters and the 40 meter beam directly above it. As the Table shows, the isolation is just 35 dB. If 1500 Watts is put into the tribander at 21 MHz, the 40 meter beam will send 0.43 Watts, or +27 dBm to the second receiver. This is unacceptably high and additional isolation must be provided with filters and/or stubs.

There are some interesting numbers in the Table. For example, when the tribander is transmitting on 20, the 4 over 4 stack is picking up 0 dBm, or just 1 milliWatt. This means that two radios could be operating on 20 meters at the same time and no additional filters or stubs would be needed for protection even with full legal power being used. Of course, we would want some additional isolation to help prevent overload of the second receiver. Other combinations that will safely work are:

1. Tribander transmitting on 20 meters and second radio using the 10 meter JA antenna

2. Tribander transmitting on 15 meters and second radio using the 15 meter JA antenna.

3. Tribander transmitting on 10 meters and second radio using the 15 meter JA antenna.

There are also 6 wire antennas on the tower, 2 inverted vees for 80 meters at right angles and four ½ wave slopers for 160 meters. Isolation when the tribander is transmitting is shown in the Table 3. In each case the tribander has been rotated to the point of minimum isolation.

Table 3. Isolation between tribander and wires.

Tx	20	15	10
Rx			
160	>80	-73	>80
80EU	-54	-45	-60
80JA	-50	-46	-57

Coupling to the 160 meter slopers is minimal. This is probably due to the antenna centers being so far away from the tribander. The 80 meter inverted vee centers are quite close to the tribander. Coupling to the 80 meter inverted vees results in received powers in the +16 or +17 dBm range.

2.3.3 A Two Tower Station

Figure 5 shows the two tower setup at W2VJN. The spacing is 350 feet and the small tower is northwest of the big tower. Thus all of the fixed JA antennas on the big tower point almost directly at the small tower. When any rotary is pointed at Europe, it is ends-on to the other tower. Note that the wire antennas on the larger tower are not shown.

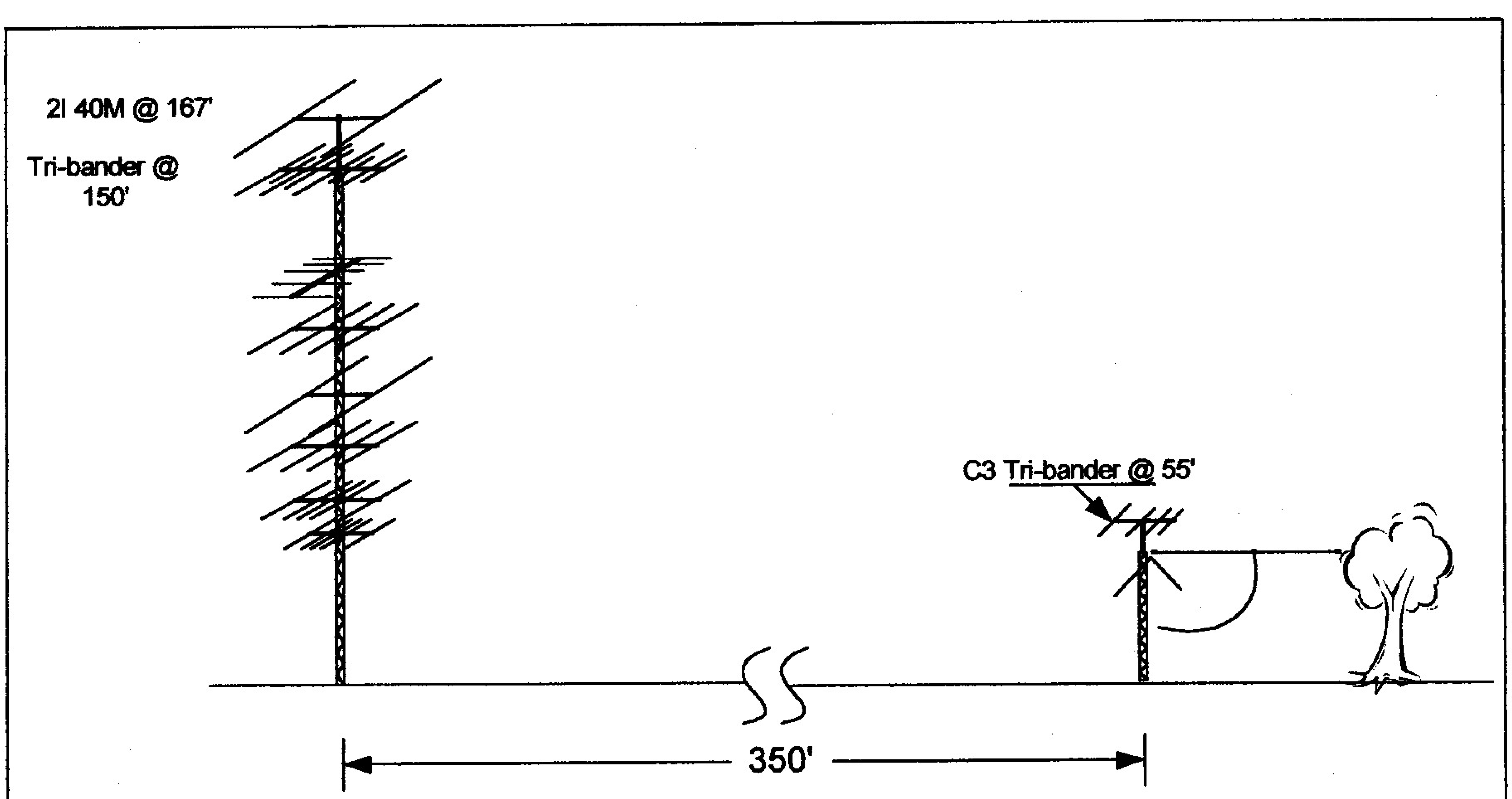


Figure 5 The two tower setup.

Table 4 lists the isolation between towers. The column on the left lists the big tower antennas and the top row lists the small tower antennas. The big tower is transmitting and the small is receiving. Rotary antennas are facing each other. Remembering that 45 dB is our minimum allowable isolation, we can see several combinations that are trouble. There are some marginal conditions which are so close to 45 dB that they can't be ignored. The worst case is the 4 over 4, 20 meter stack looking right at the C3. These towers are spaced 350 feet and yet there is only 25 dB isolation for this case. This will put 5 Watts into the receiving radio and is clearly excessive. Even the X9 at a much higher point will put over 1.5 Watts into the receiving radio. Caution is required when antennas face each other, even when fairly far apart.

Table 4. Isolation between towers.

	Rx Antenna	80M Dipole	40M Inv V	C3 Tri-bander
Tx Band	Tx Antenna			
160	NW Sloper	-52	-44	-48
160	NE Sloper	-70	-63	-67
160	SE Sloper	-68	-61	-65
160	SW Sloper	-71	-51	-60
80	EU Inv V	-43	-66	-53
80	JA Inv V	-60	-58	-66
40	JA 2L	-59	-36	-53
40	Rotary 2L	-56	-36	-53
20	JA 4/4	57	-45	-25
20	Rotary X9	-57	-50	-30
15	JA 5L	-59	-44	-31
15	EU 5L	-70	-69	-51
15	Rotary X9	-59	-49	-35
10	JA 5L	-70	-48	-35
10	Rotary X9	-67	-50	-45

Figure 6A shows a sweep frequency response made with the tribander antennas pointing at each other. The generator was driving the X9 and the spectrum analyzer was monitoring the C3. Figure 6B shows the same sweep with the X9 on JA and the C3 on EU. We can see that the isolation is adequate for full power operation with the antennas at right angles. (Note: There are some differences in the value between the sweeps and Table 4 due to calibration methods.)

2.4 The Worst Case Conditions

Looking through the isolation Tables for the examples given, we can see that the worst case minimum numbers are 23 to 27 dB. We have previously noted that 45 dB is the absolute minimum tolerable isolation which will prevent radio damage. We have noted also that 147 dB of isolation is needed to provide a two radio setup with minimal interference. Thus the additional isolation ranges from a minimum of 22 dB to a maximum of 124 dB. This should cover the range of requirements for most situations. Next we'll look at the options available for improvement.

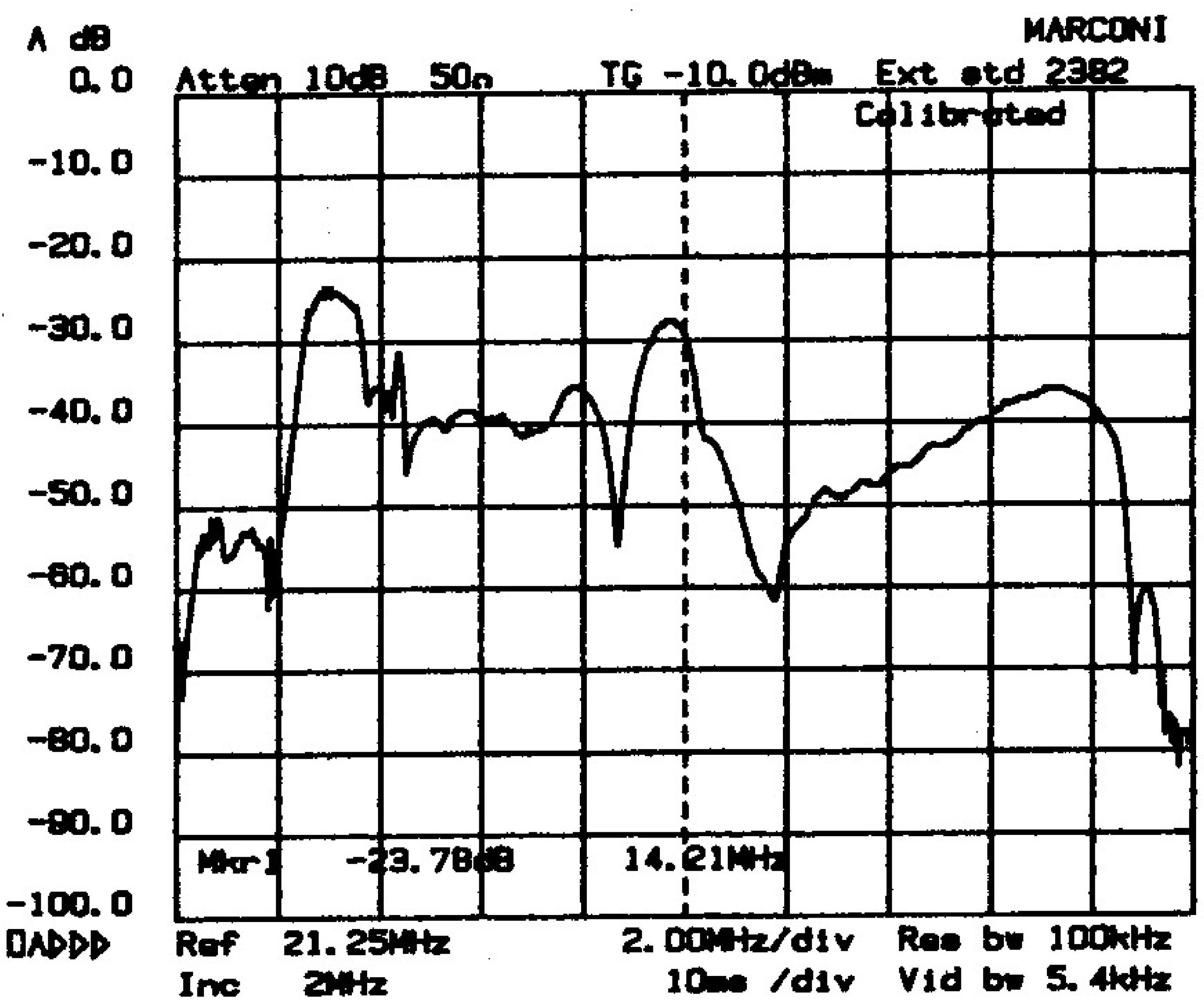


Figure 6a. Tribanders pointing at each other.

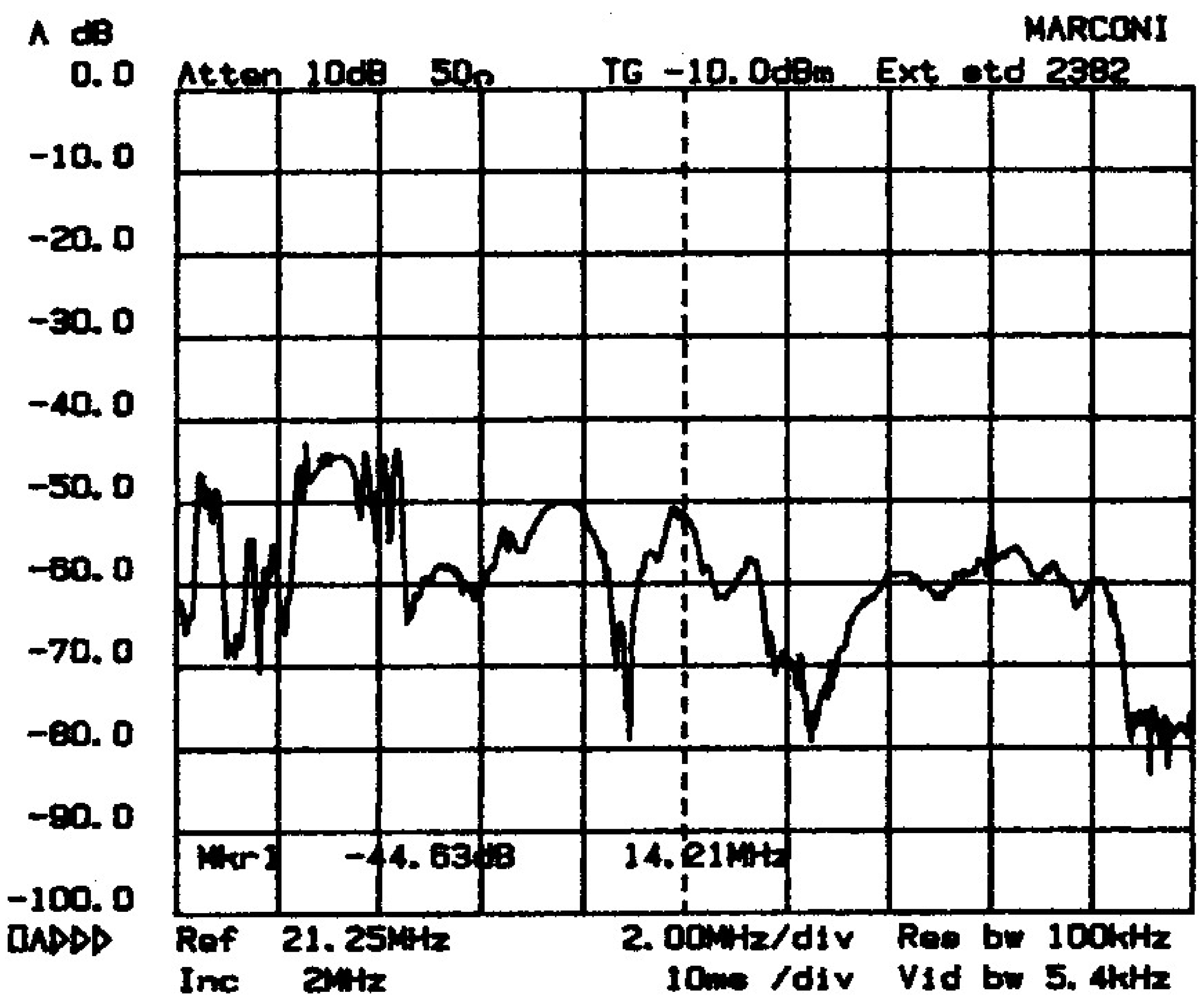


Figure 6b. Tribanders at right angles.

3.0 COAXIAL STUBS

3.1 Basics

A coaxial stub is a length of transmission line that is shorted or open at one end and connected to a circuit or another transmission line at the other end. Generally, in amateur applications the stub would be connected to a transmission line between a radio and an antenna. Stubs can act as inductors, capacitors or resonant circuits of series or parallel form, depending upon the wavelength and their length. Stubs may be used to reduce a transmitter harmonic output. Stubs also may be used to reduce receiver input signals at sub harmonics or harmonics of the desired signal. Stubs generally are cut to either ¼ or ½ wave length. Some special purpose stubs are cut to other fractions of a wave length.

One wavelength may be calculated with the following formulas:

One wavelength in feet = Vp(983.6/frequency in MHz)

One wavelength in meters = Vp(299.8/frequency in MHz)

Where Vp = velocity of propagation for the cable in use

The Vp is a function of the dielectric constant for the insulation between the inner and outer conductors of coaxial cable. The Vp for some common cables is listed in Table 5.

Table 5 Coax cable velocity factors

Cable	Vp
RG-58	0.665
RG-213	0.665
RG-8x	0.78
LMR-240	0.84
LMR-400	0.89
RG-142	0.695

Vp can be calculated for other dielectrics from the following formula:

$$Vp = 1/\sqrt{\epsilon}$$

Where ϵ = the cable insulation dielectric constant

Note that there can be some variation in Vp from cable to cable of a different manufacture. This is particularly true for foam types of insulation. Vp can also vary with frequency. If high precision is required, it is best to measure Vp for the cable in question.

Stubs are usually connected to a transmission line carrying power to and from an antenna. In some cases they are used to reduce the harmonic energy emanating from a transmitter. In other cases they are used to reduce the off frequency energy arriving at a receiver from another source. Operation relies on some fundamental properties of transmission lines. These principals are:

1. The input impedance of ½ wavelength line is the same at both ends. Thus if it is open circuited at the far end, the input impedance is very high. If shorted, the input impedance is very low.

2. The input impedance of a ¼ wavelength line is opposite the impedance at the far end. If it is open at the far end, the input impedance is very low. If shorted, the input impedance is very high.

We can observe these characteristics in Table 6 below. The stubs are cut for the 40 meter band.

Table 6 40 Meter stub characteristics

BAND	1/4 WAVE SHORTED	1/4 WAVE OPEN	1/2 WAVE SHORTED	1/2 WAVE OPEN
80	NOT USED	NOT USED	OPEN CKT	SHORT CKT
40	OPEN CKT *	SHORT CKT	SHORT CKT	OPEN CKT *
20	SHORT CKT	OPEN CKT	SHORT CKT	OPEN CKT
15	OPEN CKT	SHORT CKT	SHORT CKT	OPEN CKT
10	SHORT CKT	OPEN CKT	SHORT CKT	OPEN CKT

It can be seen that two types of stubs present an open circuit to the 40 meter transmission line. They are marked with an asterisk. These are the ¼ wave shorted and the ½ wave open stubs. The other stubs would not be usable on 40 meters. The ¼ wave shorted stub presents a short to 20 meter and 10 meter harmonic energy and is useful for reducing transmitter harmonics.

The ½ wave open stub also presents an open circuit to the 40-meter transmission line. As the Table shows, it will reduce any 80-meter energy on the line. This typically would be used to protect a 40-meter receiver from an 80-meter transmitter.

The ¼ wave shorted stub normally would be connected to the amplifier output. The ½ wave open stub would not need to be connected to the amplifier output as it affects only received signals. It can be used at the transceiver output before the amplifier. This can sometimes be an advantage, as smaller stubs can be made with RG-8x or RG-58 which might heat up under some higher power conditions. The ½ wave open stub also will reduce the transmitted wide band noise on 80 meters when transmitting on 40.

Figure 8a shows a simulation of the frequency response obtained with a 40 meter ¼ wave shorted stub. Note the null at 14 MHz. Additional nulls occur at all even harmonics of 7 MHz. Note the null at 28 MHz.

Figure 8b shows a simulation of the response obtained with a 40 meter ½ wave open stub. Note the first null at 3.5 MHz and additional nulls at multiples of 3x, 5x and 7x 3.5 MHz.

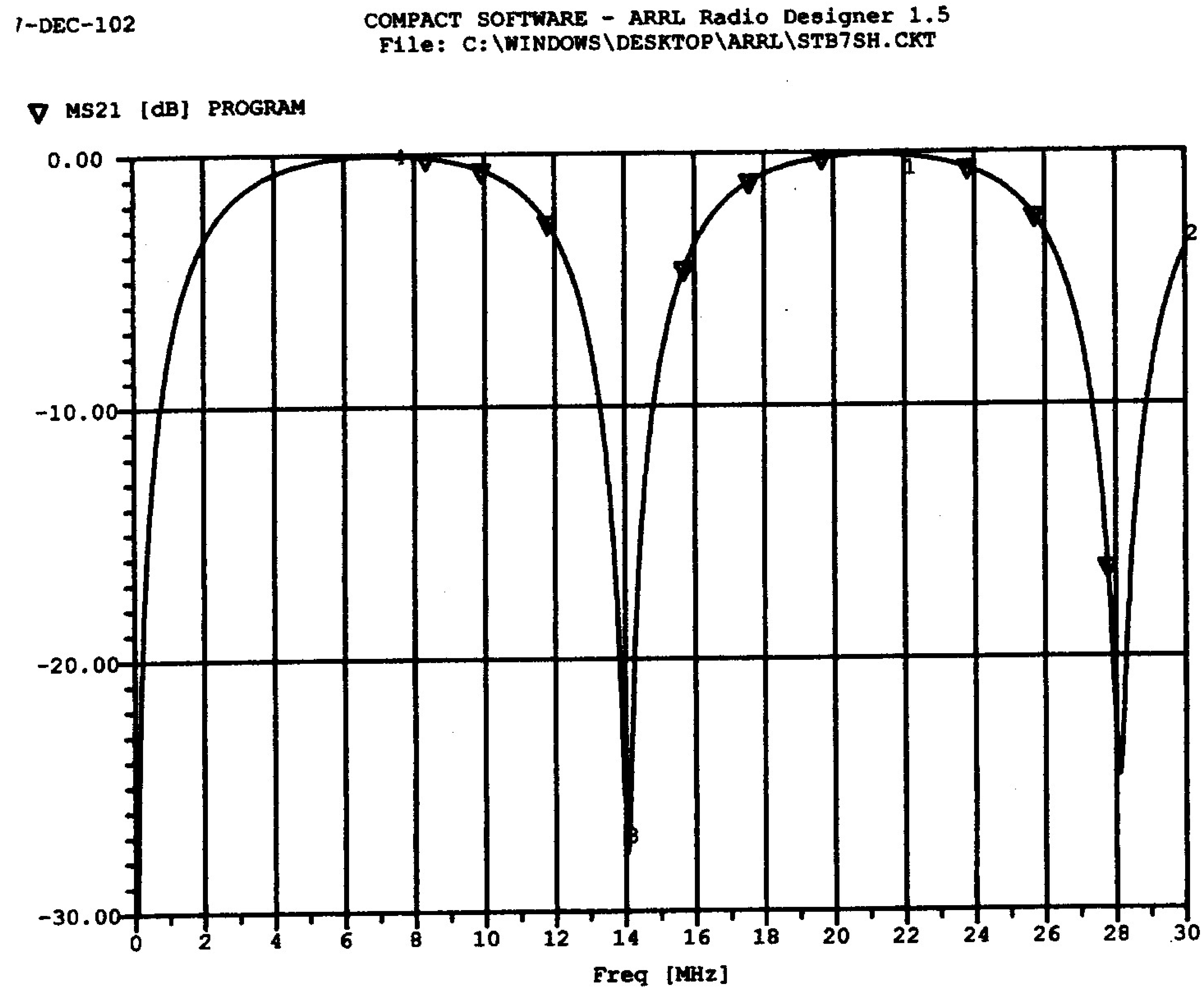


Figure 8a 7 Mhz shorted ¼ wave stub.

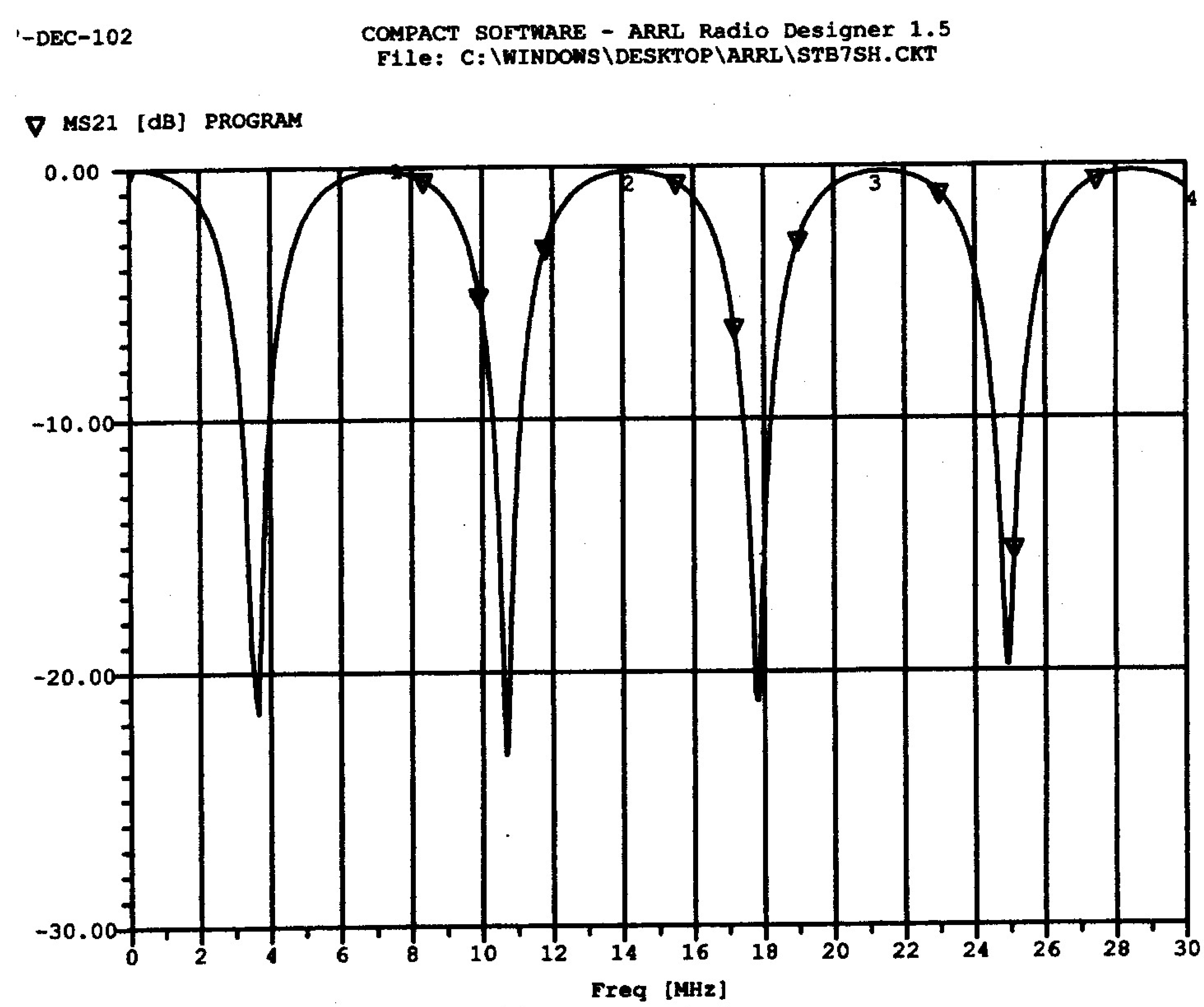


Figure 8b 7 MHz open ½ wave stub.

The reactance seen at the input to a stub depends upon its length and whether it is shorted or open. A stub less than ¼ wave long presents a capacitive reactance at its input if it is open and inductive if shorted. As the stub is made longer, the type of reactance reverses every ¼ wave. Table 7 shows the input reactance vs length for stubs from 0 to 1 wavelength long.

Table 7 Stub reactance vs length

Length		**Reactance type**	
In Wavelength	**In Degrees**	**Open End**	**Shorted End**
0 to 1/4	0 to 90	Capacitive	Inductive
1/4 to 1/2	90 to 180	Inductive	Capacitive
1/2 to 3/4	180 to 270	Capacitive	Inductive
3/4 to 1	270 to 360	Inductive	Capacitive

3.2 Using the ARRL Radio Designer Software

The ARRL software can be used for determining the response of coaxial stubs or combinations of stubs and discrete components. When designing something complex, simulating the circuit before cutting coax can save a lot of time. Figure 9a shows a simple file that can be used to simulate a pair of ¼ wave shorted stubs coupled with a 1/8 wave line. (It's ¼ wave on 28.1 MHz.) The values for K, C1 and C2 are for RG-213 cable. K is the dielectric constant for polystyrene. C1 and C2 are constants derived by using the optimize function in the software and the attenuation values for RG-213 vs frequency. The stub being analyzed is cut for 14.05 MHz. The output response (Figure 9b) shows a 66.5 dB null at 28.1 MHz.

Figure 9a A double stub file for ARD.

```
BLK
CAB 1 2 0 0 Z=50 P=1.774M K=2.26 C1=0.2156 C2=0.0531
CAB 1 3 0 4 Z=50 P=3.548M K=2.26 C1=0.2156 C2=0.0531
SHO 3 4
CAB 2 5 0 6 Z=50 P=3.548M K=2.26 C1=0.2156 C2=0.0531
SHO 5 6
PROGRAM:2POR 1 2
END
FREQ
ESTP 27MHZ 30MHZ 500
END
```

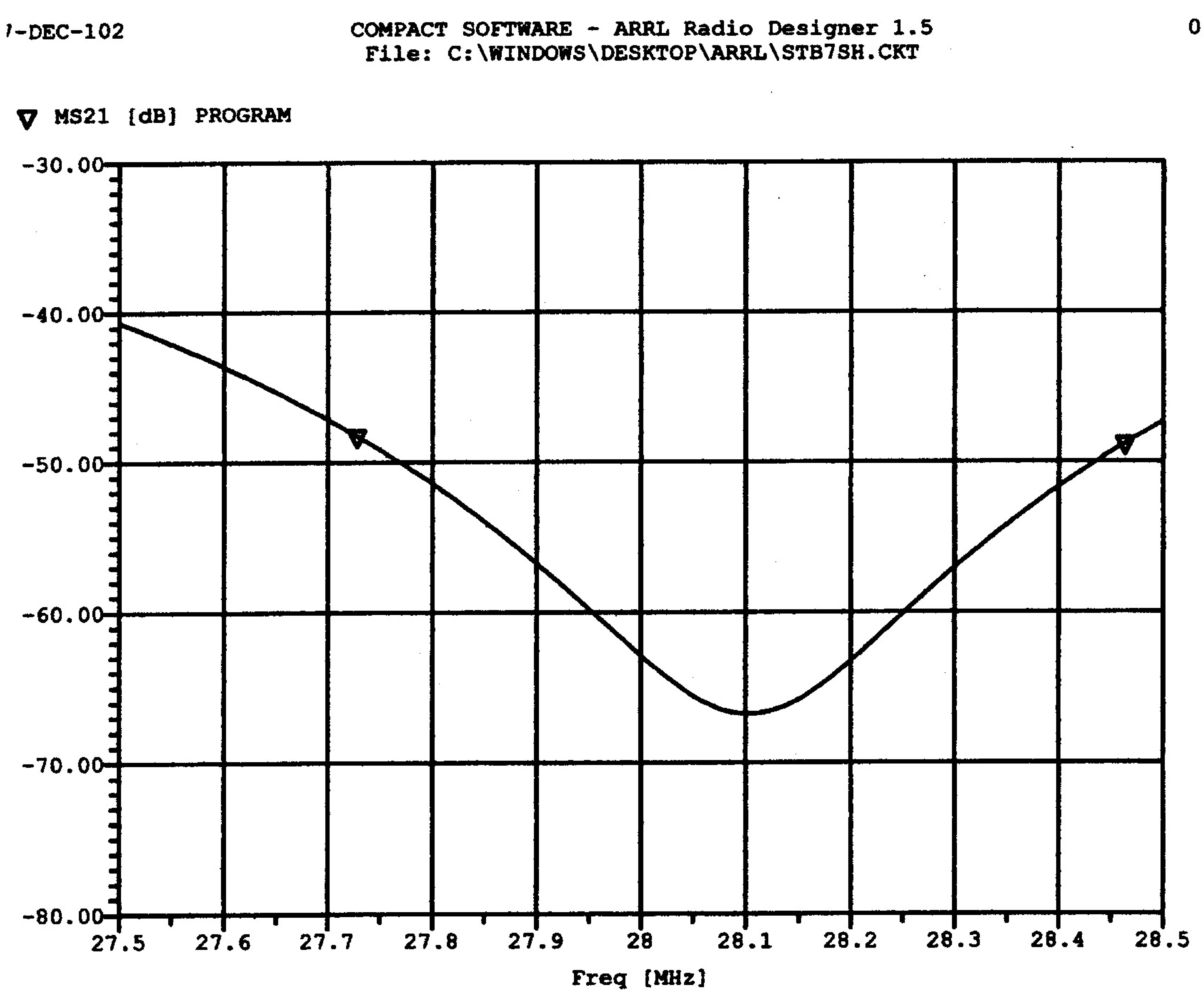


Figure 9b The ARD response for the file in figure 9a.

3.3 Making Stubs - Rough Cutting

Coax can be measured by stretching it out on a clean floor next to a measuring tape. Unless both are stretched very straight, the accuracy will be poor. It is easy to develop an error of a foot or more in a length of 46 feet when trying to cut an 80 meter stub. For this reason the rough cut should be made oversized by 5% or more.

Cable measuring meters that are available from Hycon Mfg. Co. allow accurate coaxial measurement to a fraction of an inch in any length. This company also markets various devices for coiling cable. Figure 10 shows a homemade reel holder that the author uses. It holds a 500 foot spool of RG-213 or a 1000 foot spool of RG-8X.

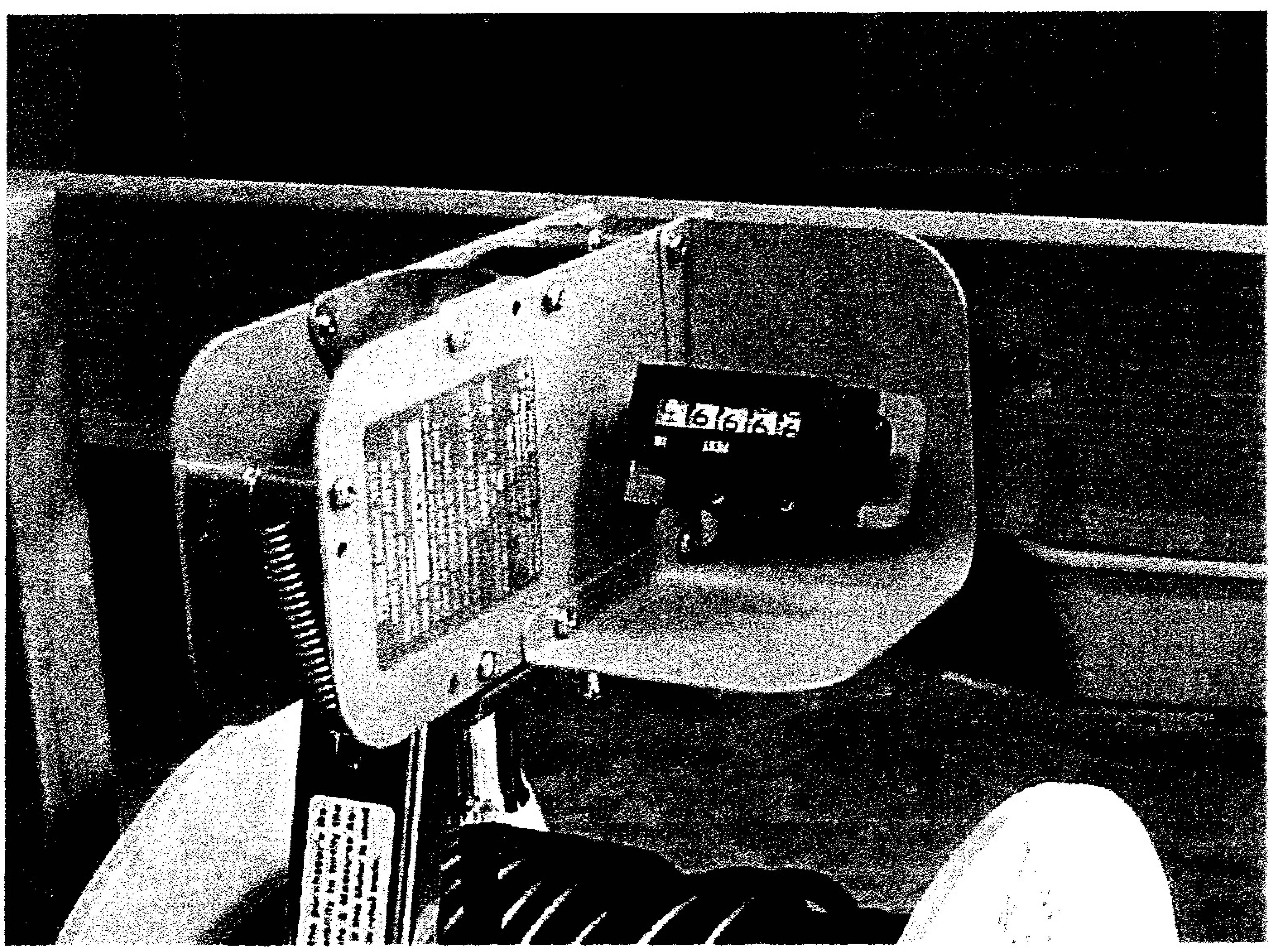


Figure 10 The Hycon cable meter with a 500 foot roll of RG-213 mounted.

3.3.1 What Level of Accuracy is Required for the Final Trim?

The null frequency on the second harmonic is of primary importance. The cutting accuracy directly determines the null frequency. The accuracy required to cut the stub within 100 kHz on the HF bands is shown in Table 8.

Table 8 RG-213 cutting accuracy

BAND	Length Deviation/100 kHz
1.8 MHz	16 inches
3.5	8
7	4
14	2
21	1.5
28	1

For a single stub, cutting to the listed deviations will reduce the null by 3 dB at the desired frequency. When multiple stubs are cascaded the maximum attenuation will be obtained if each stub is cut to the indicated accuracy or better. These numbers are typical for RG-213U and will vary somewhat for cable with a different velocity of propagation.

Table 9 shows the calculated lengths for ¼ wave of RG-213. The actual length used for the rough cut by the author is also shown. Measurements are made with a cable meter and are quite accurate. The actual figures represent the minimum length that will guarantee a stub that is not too short for the bottom of the band.

Table 9 Rough cut lengths for RG213

BAND	Calculated	Rough Cut
160	90' 10"	95'
80	46' 8"	47' 9"
40	23' 4"	24' 6"
20	11' 8"	12' 6"
15	7' 9"	8' 6"
10	5' 10"	6' 6"

3.3.2 Tips on Installing PL-259 Connectors

Installing PL-259 connectors can be done easily if the proper tools are used. A tool is available from various vendors that will cut the jacket, shield and insulation in one operation. The easiest connectors to install are the USA-made silver Teflon types with a gold plated center pin. They are available from many sources at a minimal cost. After the cable end is prepared, a small amount of grease applied to the end of the jacket will allow the connector to be threaded onto the cable easily. A 100 Watt temperature controlled soldering iron with a ¼ inch tip will do a nice job on the soldering. See the Sources section at the end of the booklet for references to these products.

3.3.3 *Cutting to Frequency*

One end of the rough cut stub should have a connector installed. With the stub connected to a measuring device, small amounts of cable are cut off until the desired null frequency is reached. The measurement may be made to an open circuit null frequency or a short circuit null frequency. Thus if the desired stub is a short circuited ¼ wave, it may be cut as an open circuit stub at the ½ wave frequency. For example, if a 40 meter shorted ¼ wave stub is being made, the desired null frequency would be on 20 meters. If it were being cut as an open stub, the null frequency would be on 40 meters. Once cut, it can be shorted and rechecked.

If a quantity of stubs is being made, a cable cutting tool is a great help. They are quite reasonable in price and make the job easier. While measuring the null frequency, the cable cutter can cut half way through the coax to short it and the frequency can be noted. If additional trimming is necessary, the process can be repeated.

Using 40 meters as an example, we have learned that a cutting accuracy of about 4" in a 46 foot stub, or 0.7%, is required to place the null within 100 kHz. If the null is viewed on a network analyzer the cable may be cut with extreme accuracy. The sweep response display allows one to creep up on the correct null frequency with a series of cuts. Resolution of a kHz or less and a fraction of a dB make cutting accuracy a non-problem. It is quite easy to place the null within 10 kHz when using a network analyzer. While modern network analyzers sell for many kilo-bucks, the old HP 8407A network analyzer and 8412A display cover 100 kHz to 110 MHz and can be purchased for $100 or less on the used equipment market. An 8601A sweep generator is required also and is readily available at a bargain rate.

An antenna analyzer such as the MFJ-249 can be used to measure stubs fairly accurately. Two methods may be used.

A 50 ohm (or 47 or 51 ohm) resistor is placed in series with the center conductor of the stub and the shield is grounded. Very short leads should be used for best accuracy. The measured VSWR will be minimum at the stub null frequency. Again, using 40 meters as an example, it is possible to measure the null frequency on 20 meters to about 0.25%. This represents a cutting accuracy of about 1.5" or 37.5 kHz on 40 meters.

Similar results may be obtained without using the resistor if the X scale is used. At the null frequency the X will go to zero.

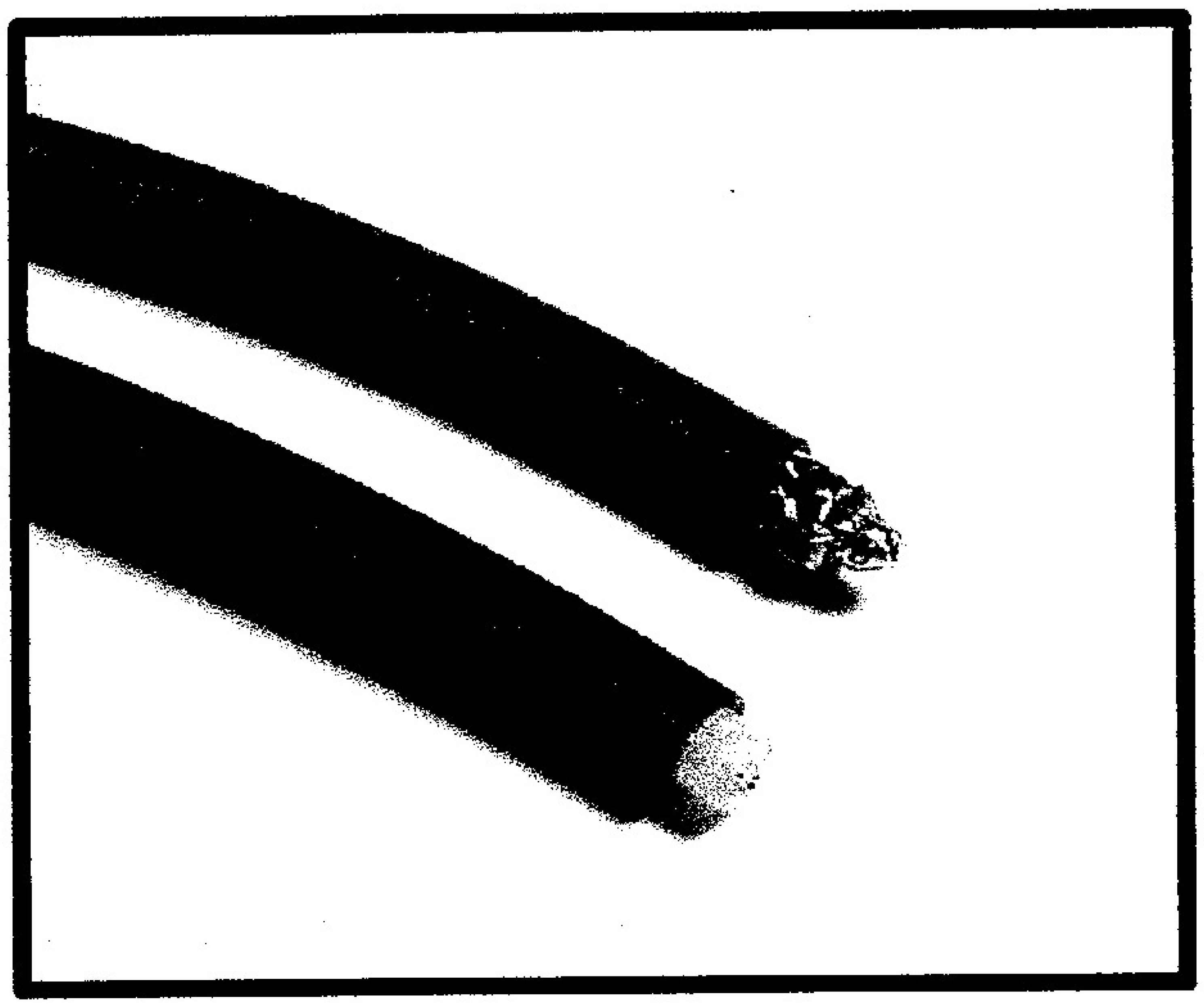
Another very accurate instrument is a spectrum analyzer and tracking generator combination. The older HP instruments can be a valuable addition to the workbench for many reasons. The HP 141T main frame with an 8553B RF plug in and an 8552B IF section are useful for frequencies from 100 kHz to 110 MHz. It's a bit more versatile than a network analyzer, as it may be used for examining transmitted spectra of CW or voice transmitters. The tracking generator for sweeping stubs is an HP-8443A.

Many of the plots that are included in this writeup were made using a computer controlled DDS (direct digital synthesizer) as the source and a log amplifier detector. The pc boards and components were purchased as a kit from a source in Australia. See the Source listing at the end of the booklet.

3.3.4 Terminating the coax.

The first step in applying a short circuit to the end of the coax after final cutting is to strip about ½ inch of outer jacket. Take care not to cut through any shield

Figure 11. Shorted and open terminations



wires. Carefully spread out the shield wires to gain access to the inner insulation. Cut through the insulation all around the center conductor about ¼ inch in from the end. Strip this piece of insulation off. This leaves ¼ inch of center conductor exposed. Return the shield wires to their original place and squeeze the last ¼ inch down around the center conductor. Twist the end to tighten the shield around the center conductor. Apply a liberal amount of solder.

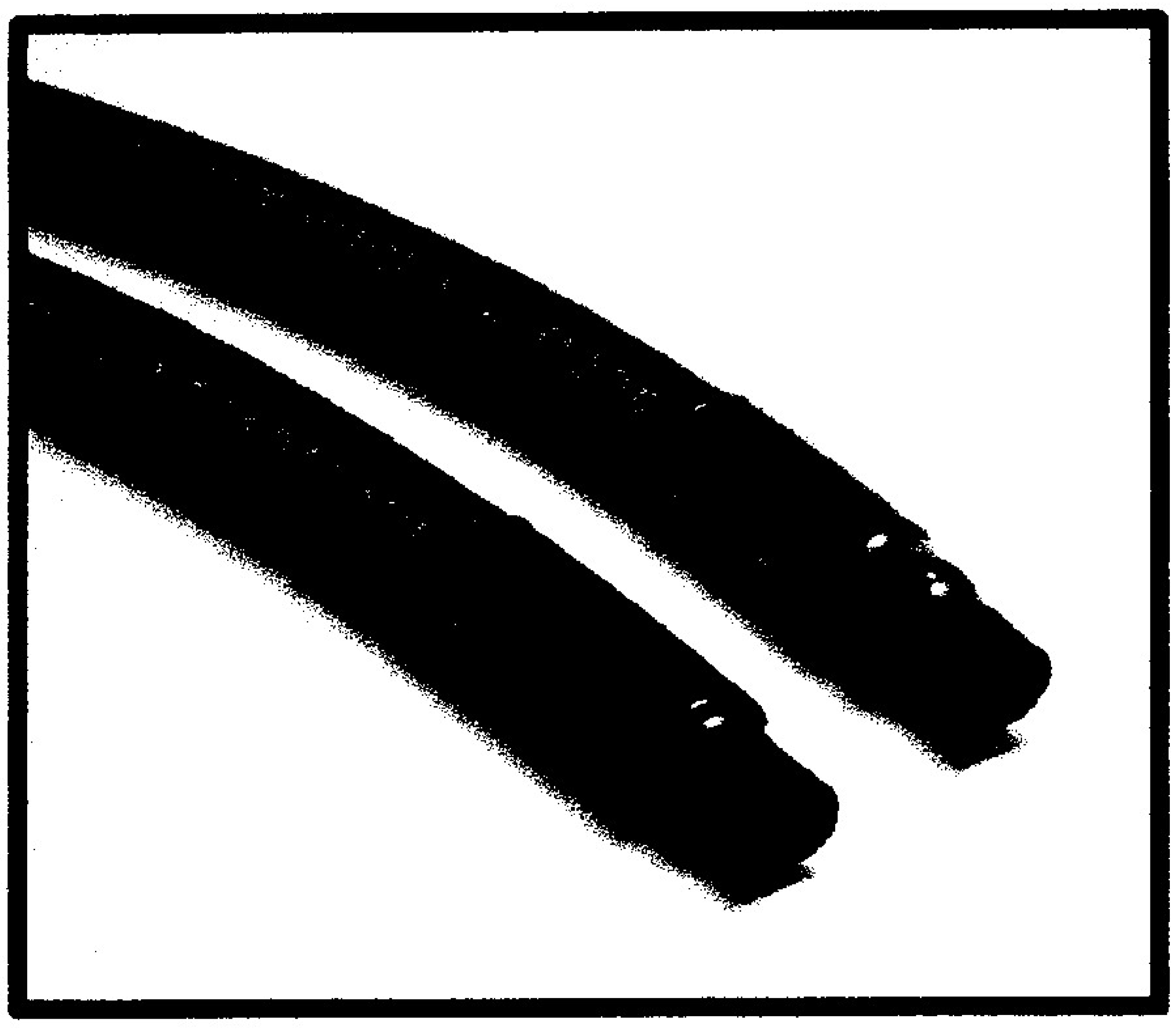


Figure 12. After shrink wrapping.

Terminating an open stub is a bit easier. Cut around the outer jacket about ¼ inch in from the coax end. Cut deep enough to go through the shield wires as well. Remove the jacket and shield wires and trim any stray wires.

It's that simple to do each kind of termination. To complete the job, apply a short length of heat shrink tubing.

These operations have shortened the stub by ¼ inch in each case. This can be compensated for in the cutting process by calculating how much lower in frequency to make the final cut before termination.

An open ended termination can act as a very small antenna if the assembly is not mounted inside a shielded container. The radiation can be stopped with a small piece of shield braid over the open end. The end of the coax needs to be insulated with shrink wrap just over the inner insulation and extending a bit past the open center conductor. A piece of shield from a scrap of coax can cover up the unshielded part and it can be soldered to the stubs shield. The whole sandwich then can be double shrink wrapped.

3.4 Types of Stubs

Table 10 lists the various kinds of stubs which may be connected in shunt with a transmission line. Stub characteristics are also listed. A numeric designation (Type) is assigned to each for reference purposes in the text.

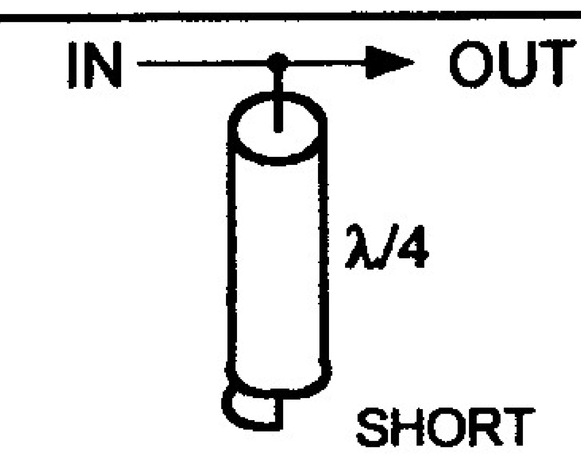
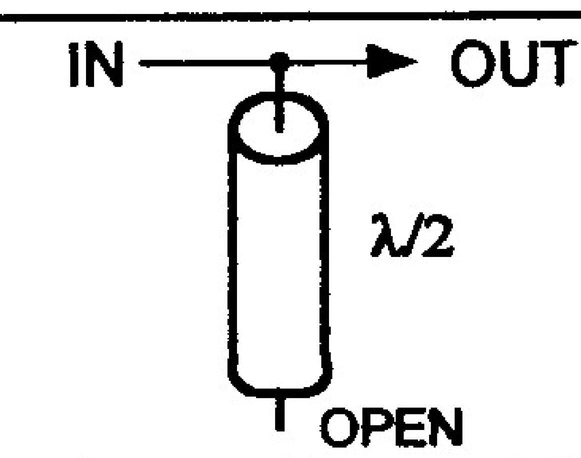
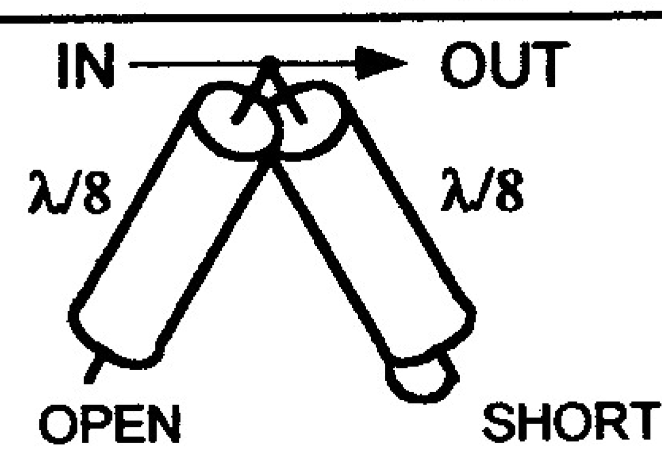
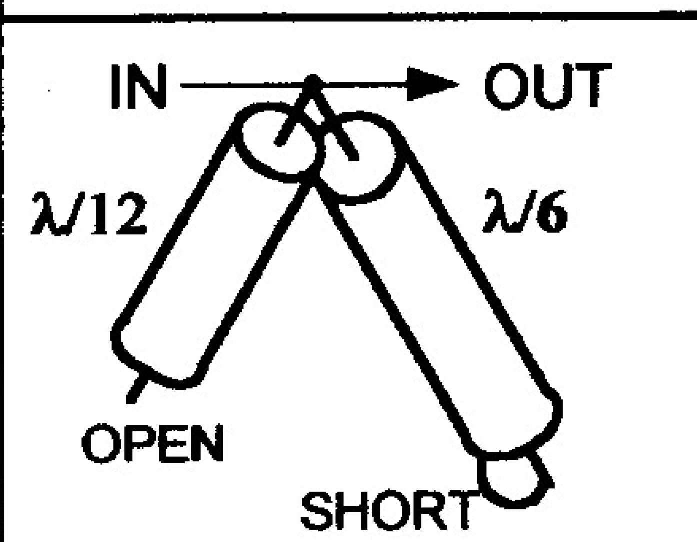
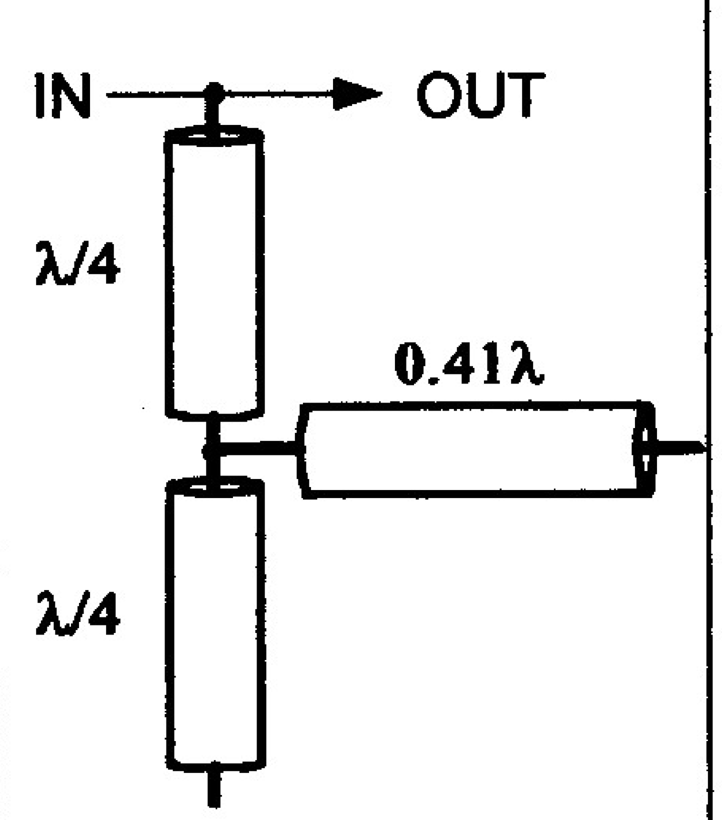
TABLE 10 SHUNT STUBS, RG-213 CABLE					
TYPE	LENGTH AT F	PASS	NULL	LOSS	DEPTH
1		F	2F,4F,6F,ETC	0.08dB	25-30 dB
2		F	F/2, 3F/2, 5F/2	0.1dB	25-30 dB
3		F	2F,4F,6F,ETC	0.15dB	30-35 dB
4		F	3F,6F,9F,ETC	0.1dB	32-38 dB
5		F	F/3 See text for other ratios.	0.1dB	32 dB

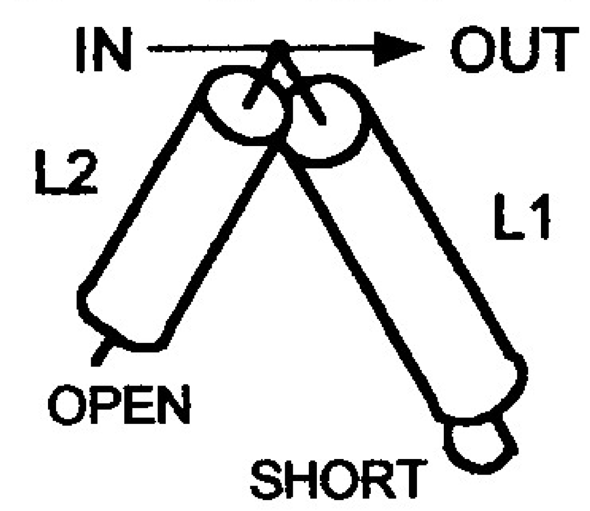
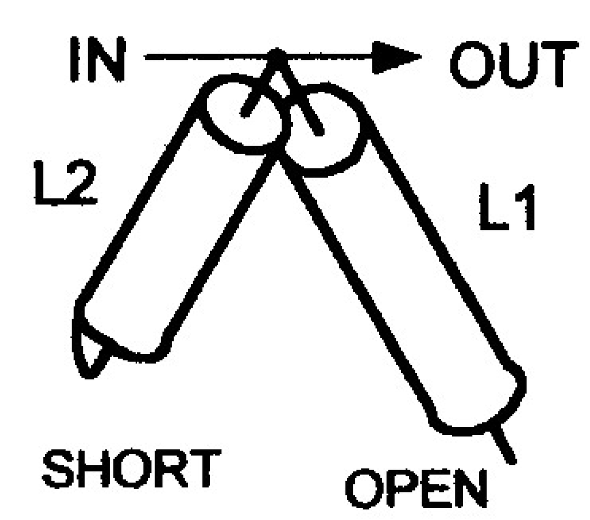
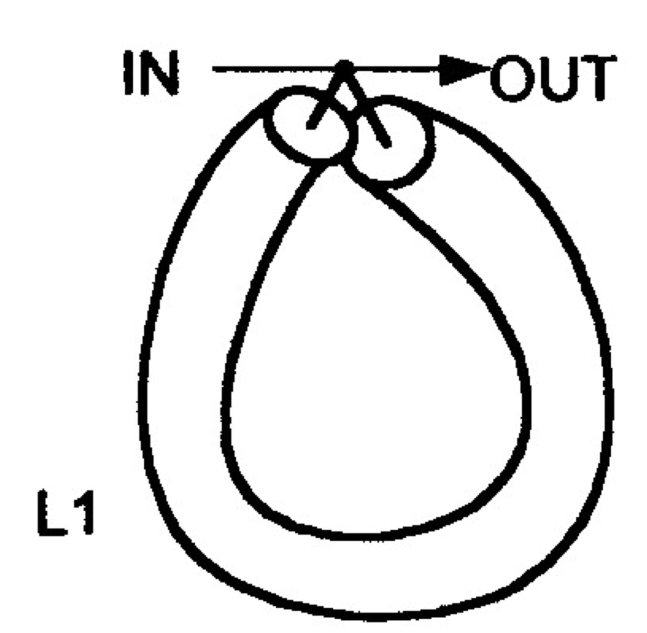
TABLE 10 CONTINUED SHUNT STUBS, RG-213 CABLE					
TYPE	LENGTH AT F	PASS	NULL	LOSS	DEPTH
6		Fp<Fn	Fn	0.08dB	28 dB
		Lengths for RG-213 Coax L1=327.05/Fn in feet L2=(163.52/Fp)-L1 in feet			
7		Fp>Fn	Fn	0.4dB	30 dB
		Lengths for RG-213 Coax L1=X163.52/Fn in feet L2=163.52(2/Fp - 1/Fn) in feet for 2Fn>Fp<3Fn			
8		F 2F	F/2 3F/2	0.25dB 0.35dB	36 dB 32 dB
		Lengths for RG-213 Coax L1=654.09/Fn in feet			

Table 11 provides names for specific kinds of stubs which correspond to the Top Ten Devices listings. Much of the data and graphs are titled with the Top Ten designation. The designation simply stands for Coaxial Stub #. Read the definition column ¼ WL 80 S as: one quarter wavelength 80 meter shorted stub, etc. The Type refers to Table 10. Performance is shown in the bands passed and nulled columns. The designation is assigned as shorthand for the following tables and diagrams.

Table 11 Stub designations

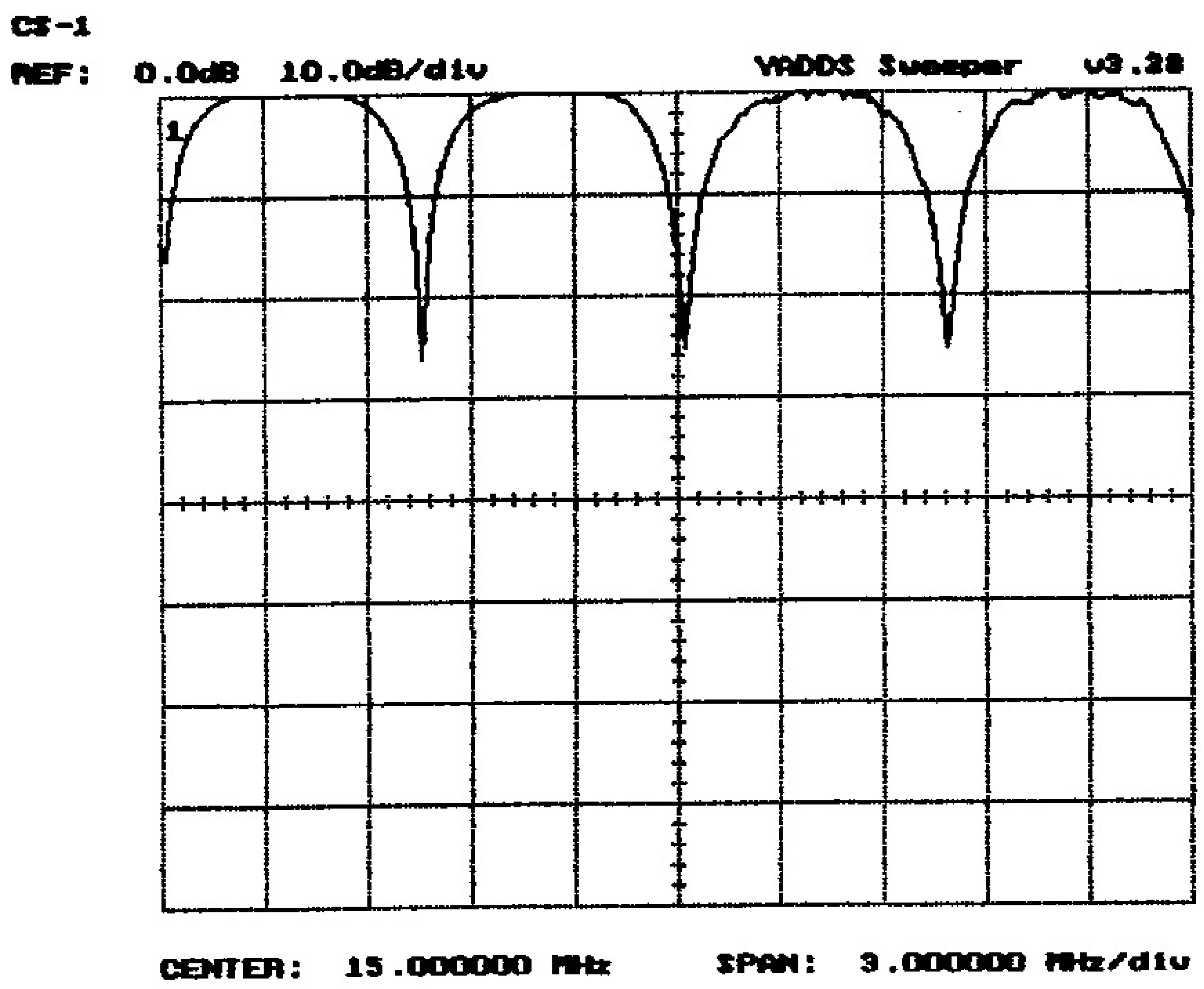
Stub definition	Type	Bands passed	Bands nulled	Top Ten #
¼ WL 80 S	1	80	40,20,15,10	CS1
¼ WL 80 O	2	40,20	80	CS2
¼ WL 40 S	1	40.15	20,10	CS3
¼ WL 40 O	2	20,10	40,15	CS4
¼ WL 20 S	1	20	10	CS5
¼ WL 20 O	2	10	20	CS6
1/6 WL S + 1/12 WL O	4	40	15	CS7/8
¼ WL 160 S	1	160	80,40,20,15,10	CS9

3.4.1 Type 1 - Single Stubs for Even Harmonic Reduction

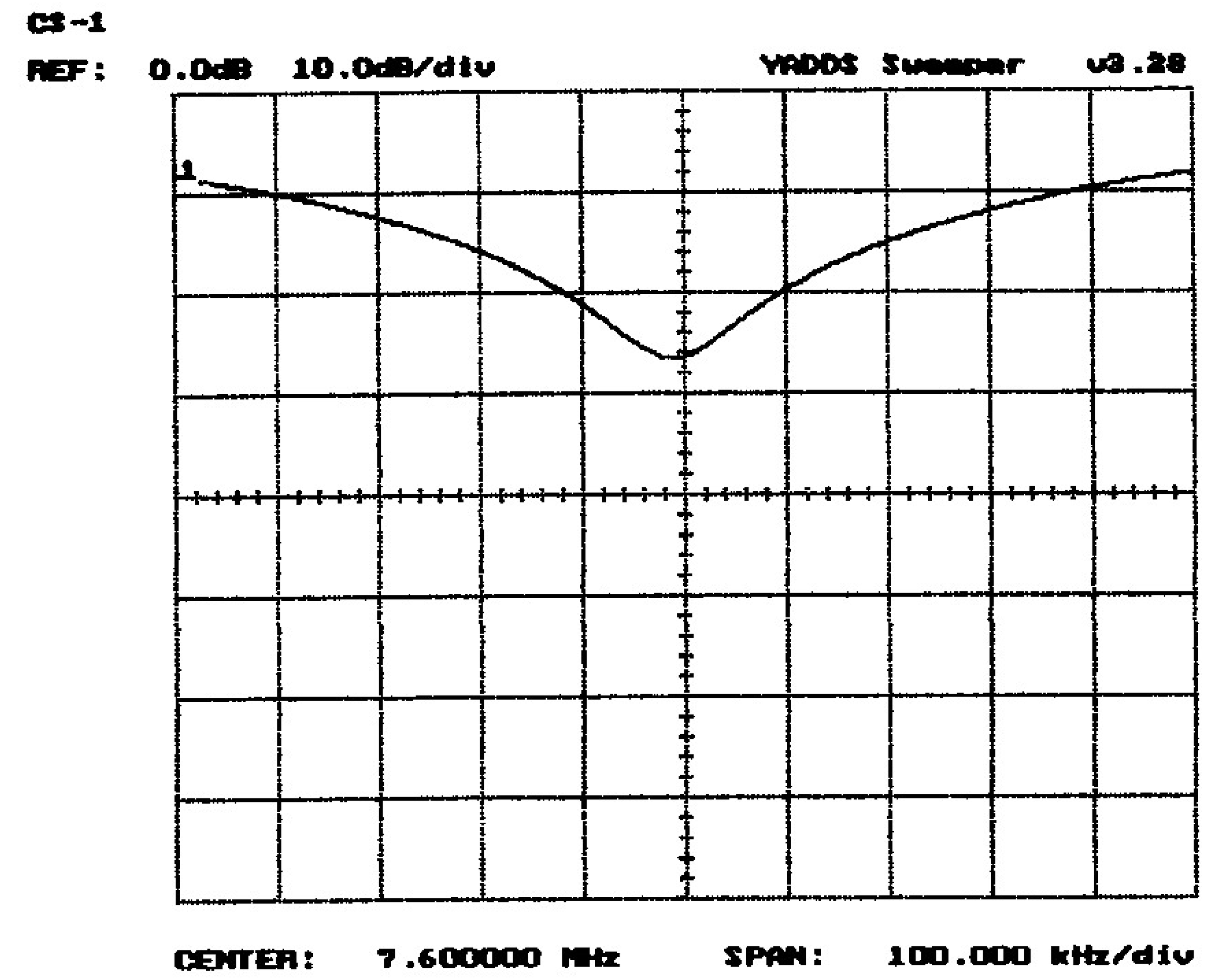
One-quarter wave, shorted stubs are usually built to null even harmonics. The following plots were taken on a network analyzer. Figure 13 shows the plots for ¼ wave, shorted stubs made from RG-213/U. Figure 13a is cut for 3800 kHz. It has nulls at 7600 kHz, 15,200 kHz, 22,800 kHz and also at 30,400 kHz, which is just off the right end of the plot. Null depth is about –25 dB in all cases. Figure 13b shows the primary null at the second harmonic. Note the –20 dB points are about 210 kHz apart.

Figure 13c is for a ¼ wave shorted stub cut for 7,200 kHz. It has nulls at 14,400 kHz and 28,800 kHz. Depth is about 30 dB for each. Figure 13d shows the primary null at 14,400 kHz in more detail. The –20 dB points are about 500 kHz apart.

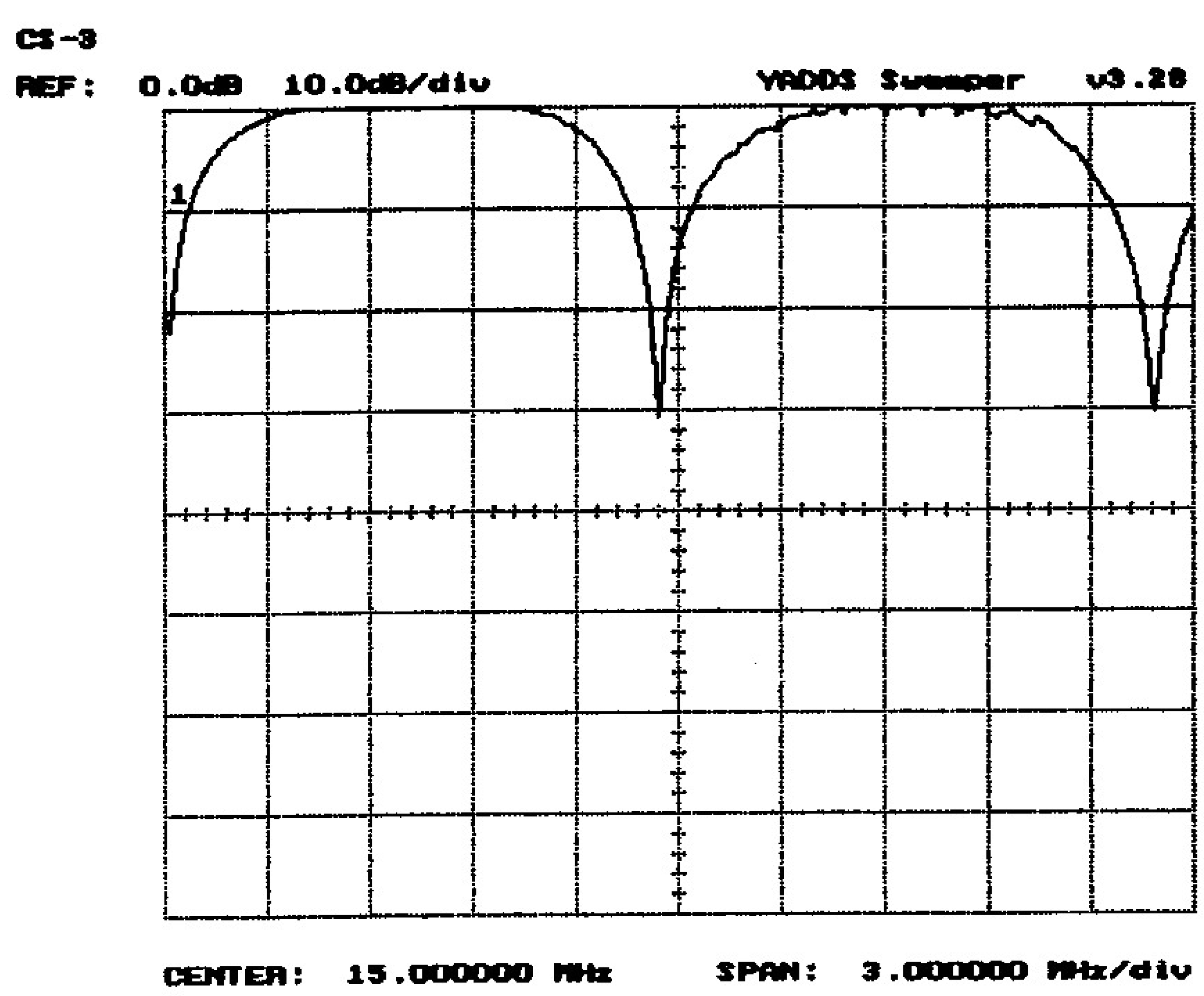
Figure 13e is for a ¼ wave, shorted stub cut for 14,200 kHz and it has a null at 28,800 kHz of about 34 dB. Figure 13f shows the 28,400 kHz null in detail. Note the –20 dB points are greater than 1 MHz apart.



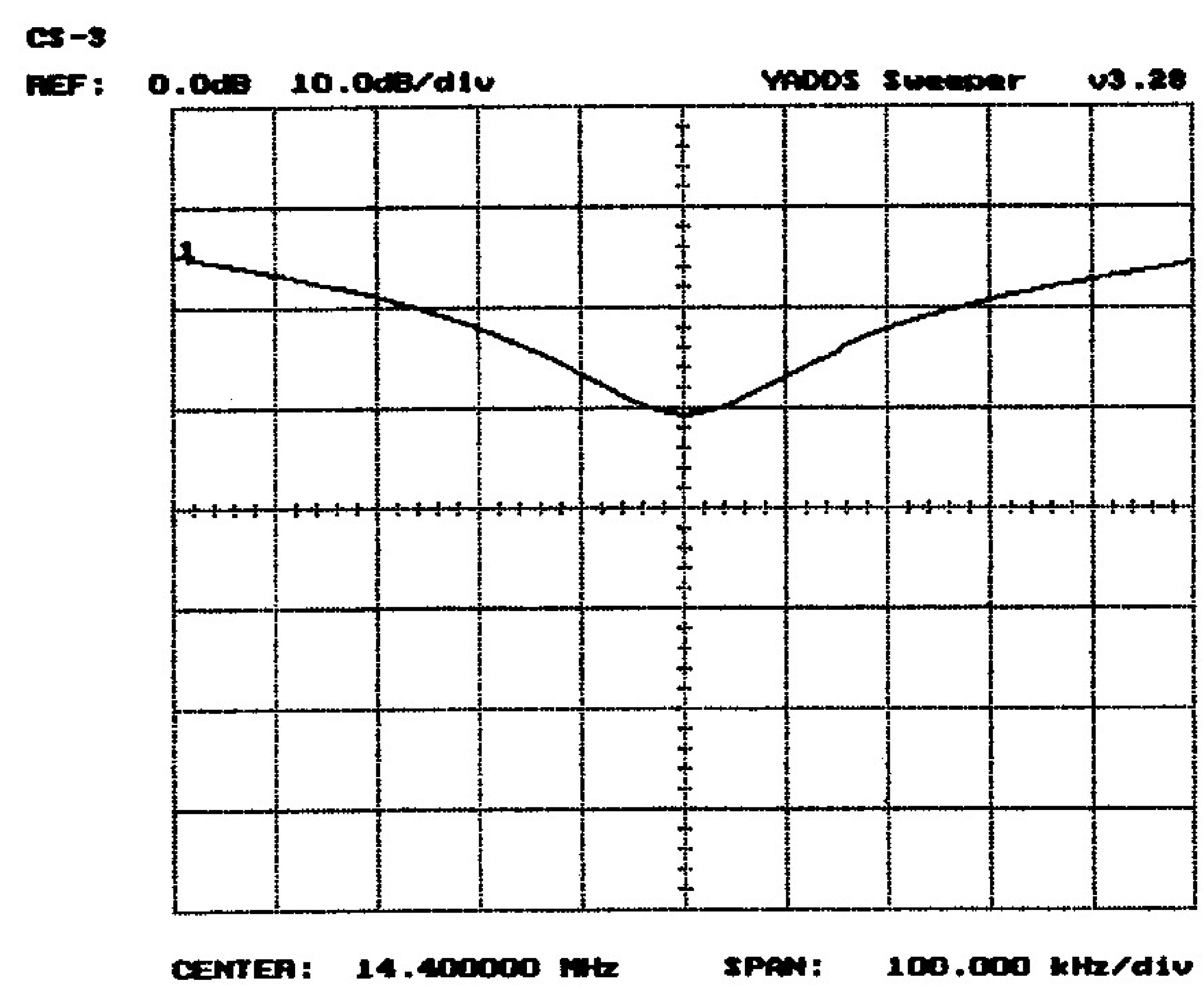
a. A 1/4 wave, 3800 kHz stub



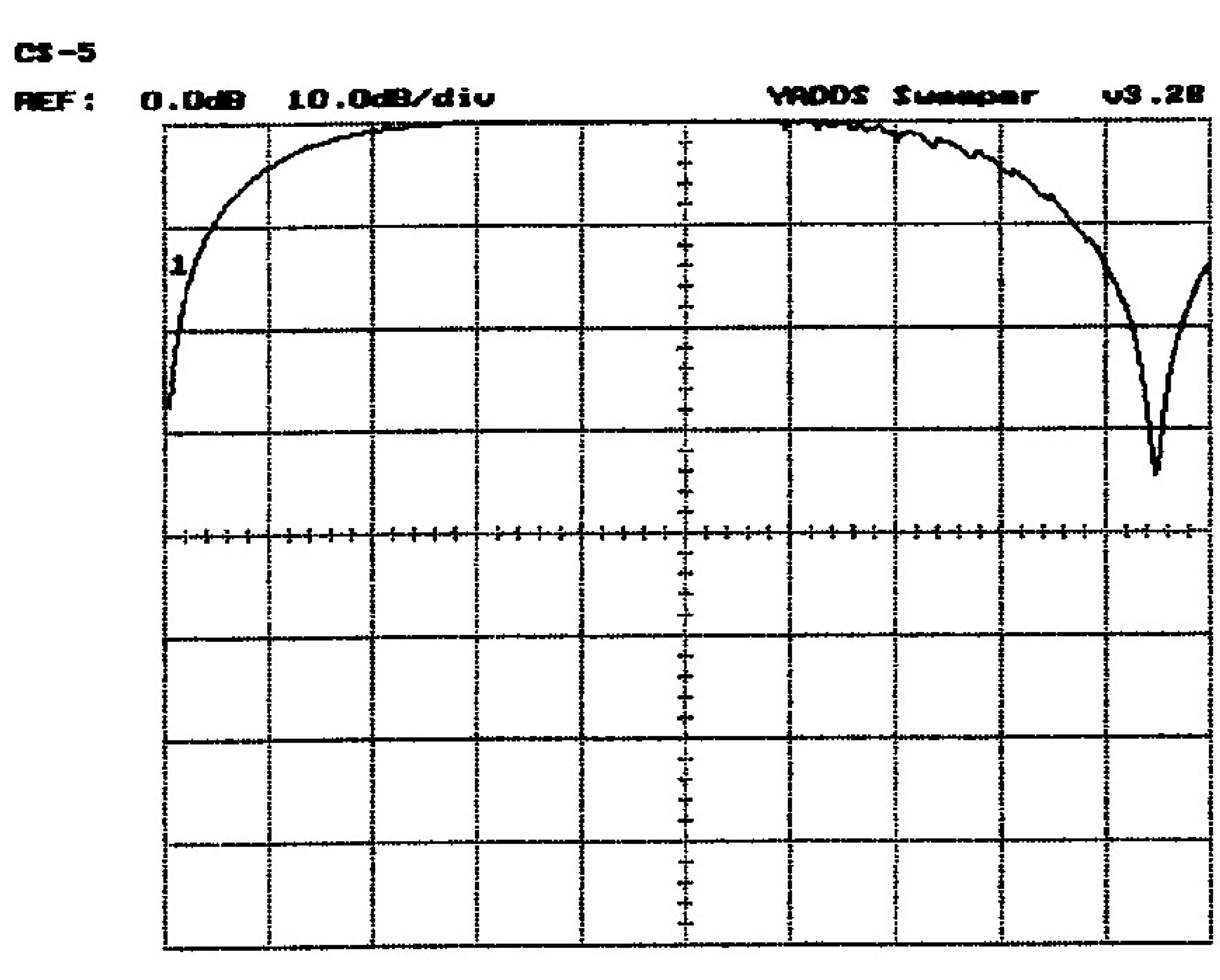
b. 2nd harmonic null for a.



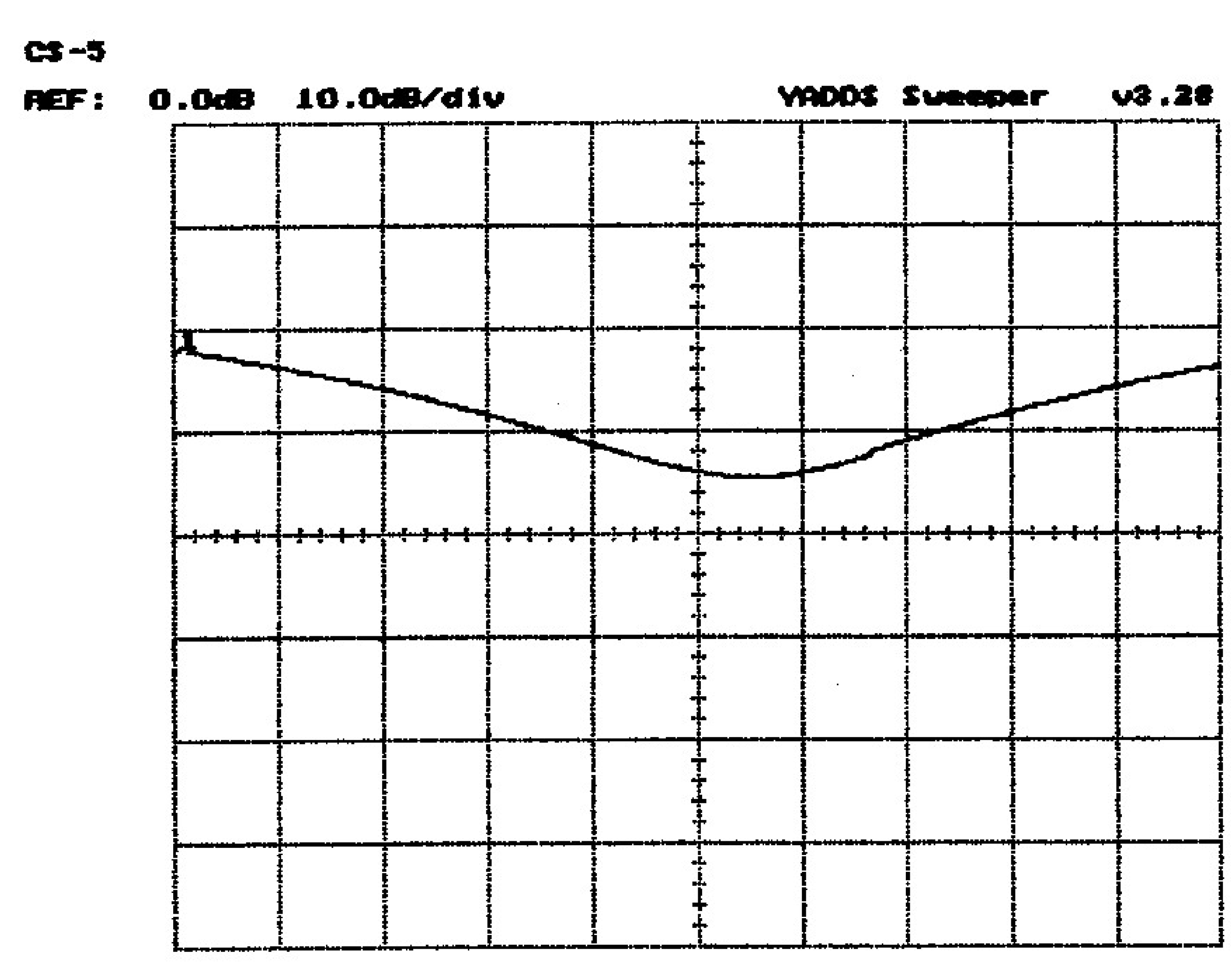
c. A 1/4 wave, 7 MHz stub.



d. 2nd harmonic null for c.



e. A 1/4 wave, 14 MHz stub.



f. 2nd harmonic null for e.

Figure 13 Frequency response for type 1 stubs.

As the cut frequency increases, so does the null depth. Note that these stubs are cut for the transmitting frequency, not for the desired harmonic null (if it happens to be different). This will produce the lowest VSWR impact on the transmitter and the maximum harmonic reduction.

3.4.2 Type 2 - Single Stubs for Sub-Harmonic Nulling

Sub-harmonic nulling is useful for protecting a receiver from a transmitter at the same location operating on a lower frequency. Open circuit, ½ wave stubs are most commonly used for this purpose. Figure 14a shows the frequency plot of a ½ wave, open circuited stub cut for 7,200 kHz. Note the nulls at 3,600 kHz, 10,800 kHz, 18,000 kHz and 25,200 kHz. The primary null at 3,600 kHz is shown in detail in Figure 14b. Note the depth at –29 dB and the –20 dB points at 210 kHz apart.

Figure 14c shows an open circuit, ½ wave stub cut for 14,400 kHz. Nulls are at 7,200 and 21,600 kHz. Null depth is –32 dB and the –20 dB points span 420 kHz.

Figure 14e is for a ½ wave, open circuit stub cut for 28,000 kHz. The null is at 14,000 kHz and is –32 dB. Bandwidth at the –20 dB points is 910 kHz. Figure 14f shows an expanded plot of the null.

3.4.3 Type 3 - 1/8 Wave Stubs - The Equations

Shorted stubs cut to ¼ wavelength present an input impedance of infinity. When cut shorter than ¼ wavelength they present an inductive reactance with a value determined by the equation below.

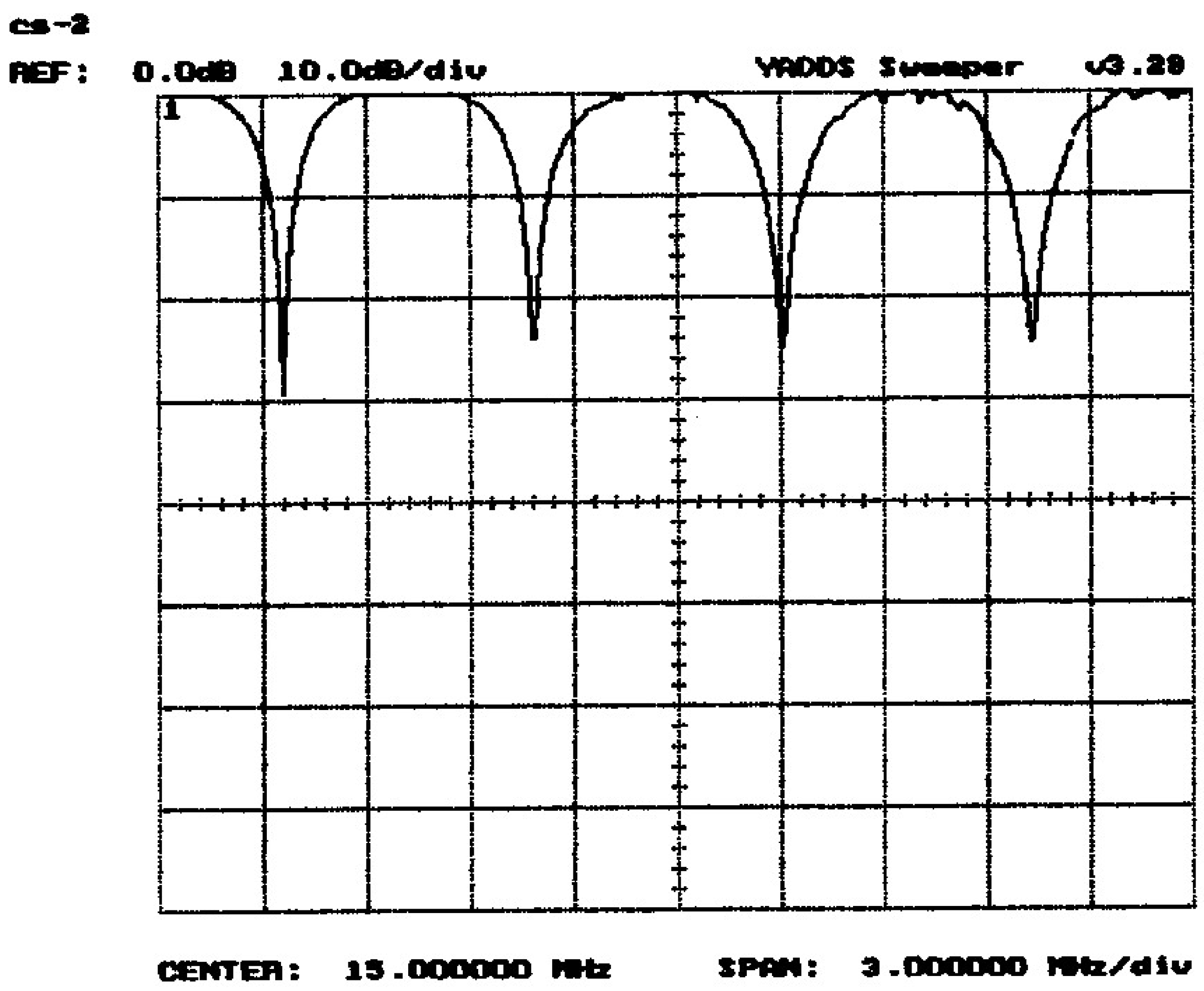
$$X_L = Z_0 \tan le$$

Where Z_0 *= the line characteristic impedance*
le = the length of the line in electrical degrees

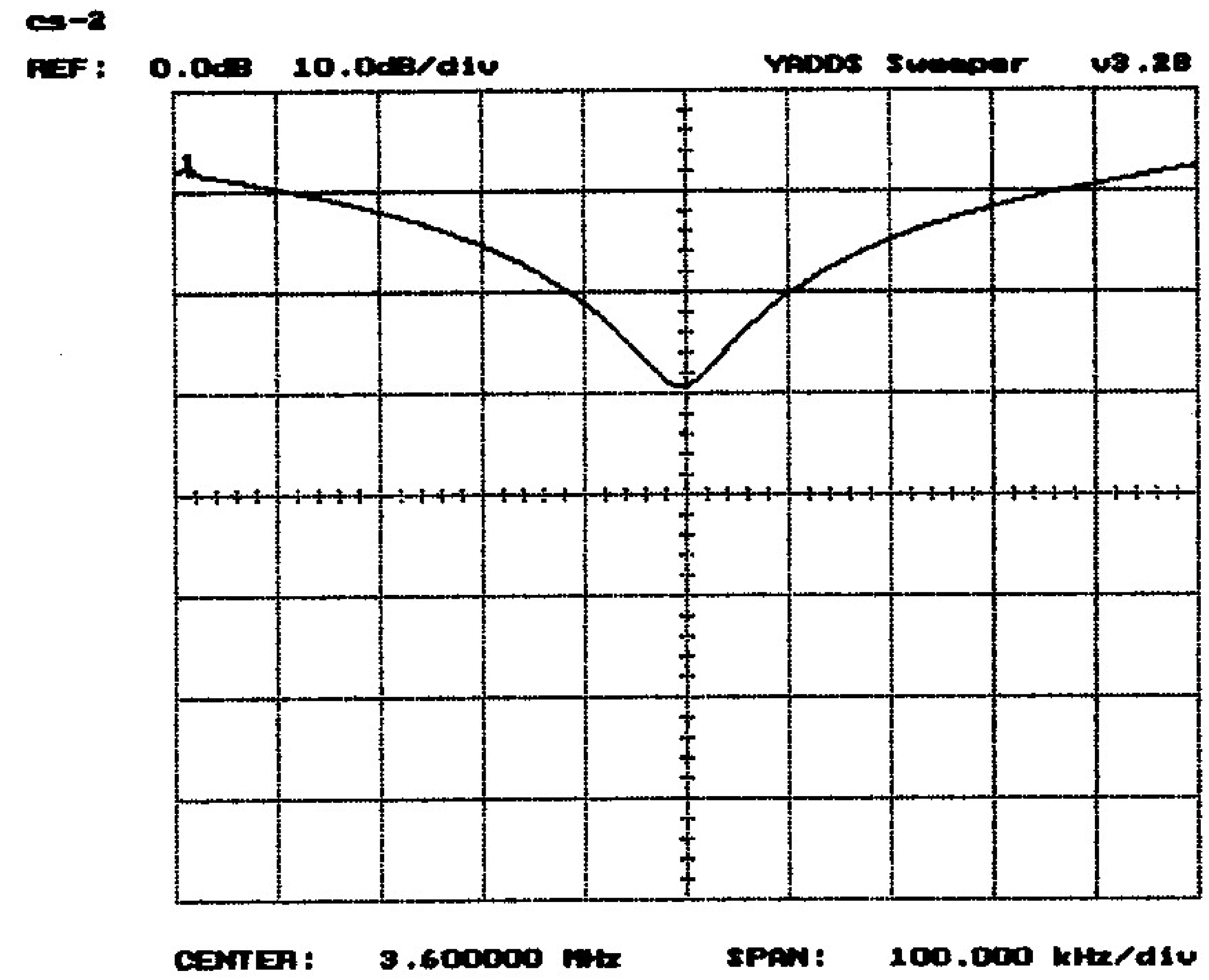
(A full wavelength is equivalent to 360 electrical degrees.)

Open circuited stubs cut to less than ¼ wavelength present a capacitive reactance of a value determined by the following equation.

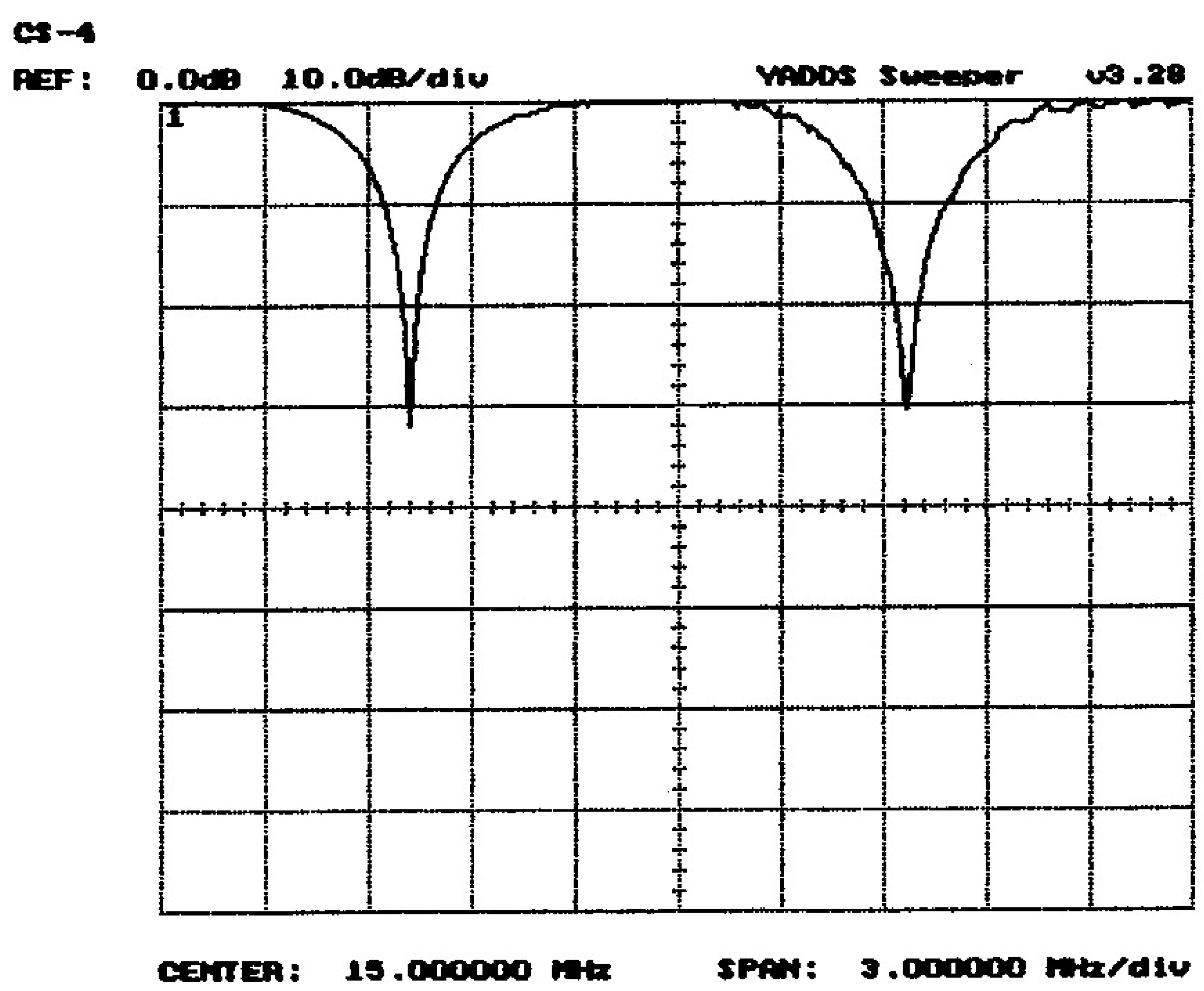
$$X_C = Z_0 \tan le$$



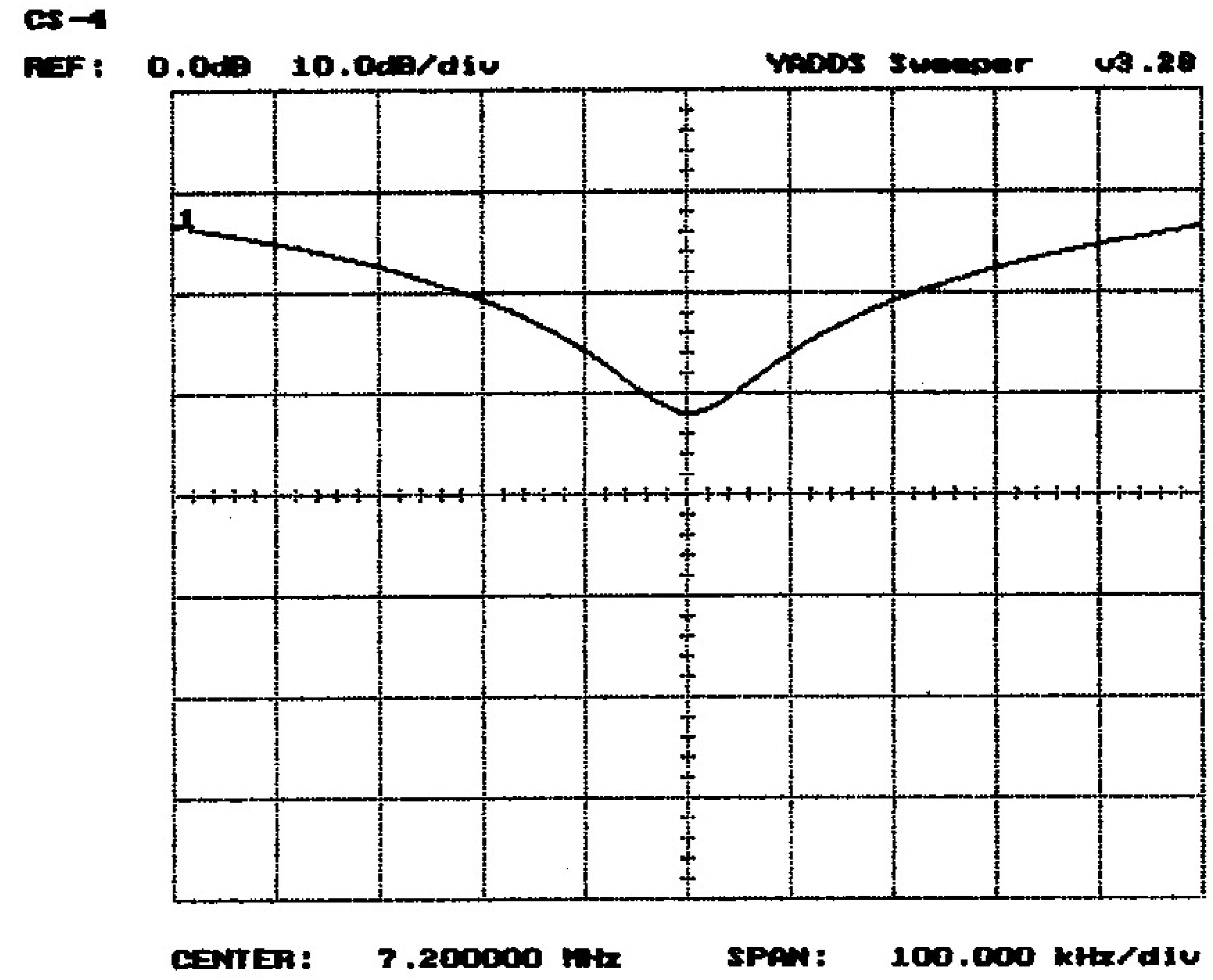
a. 1/2 wave, 7.2 MHz stub



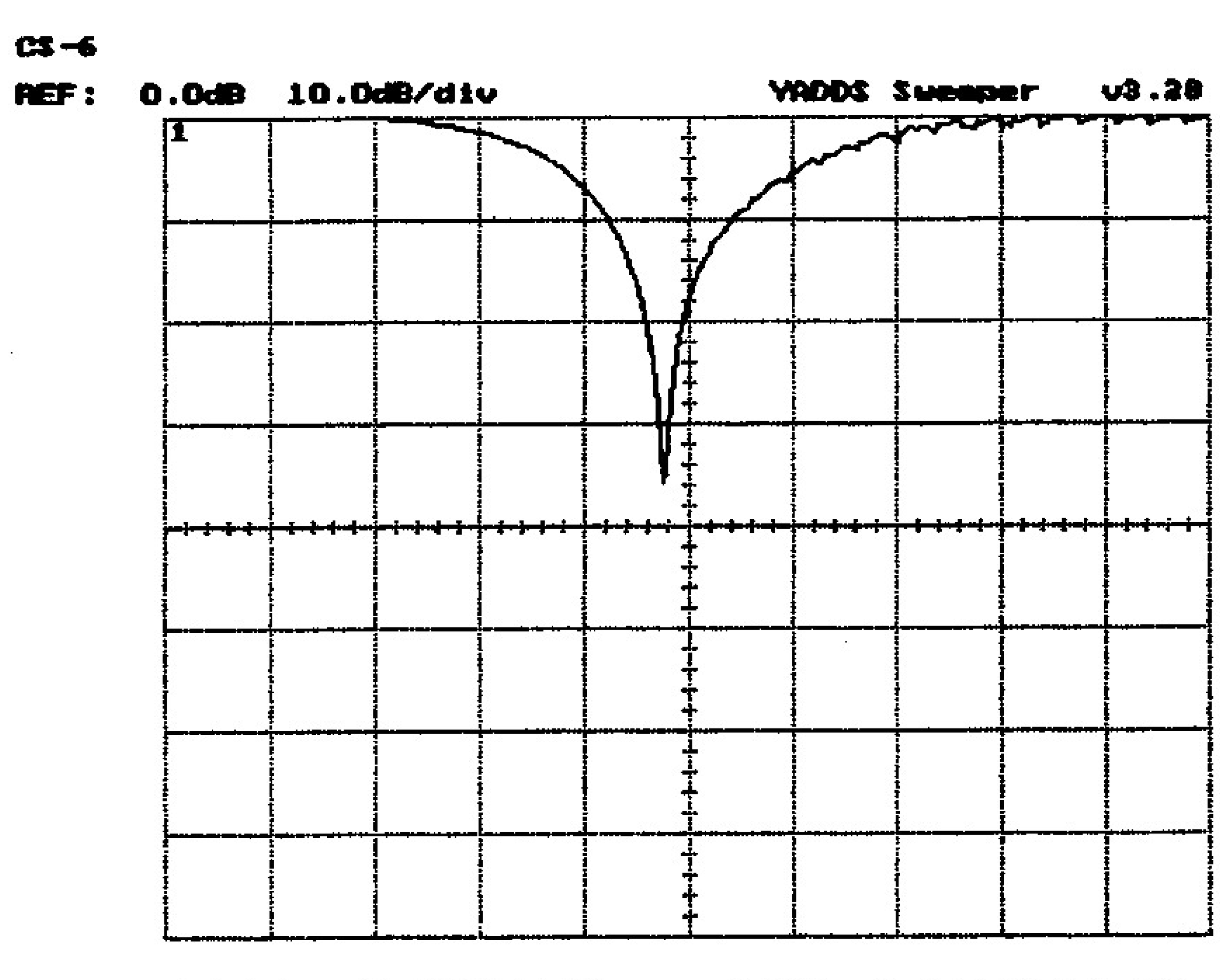
b. Sub harmonic null for a.



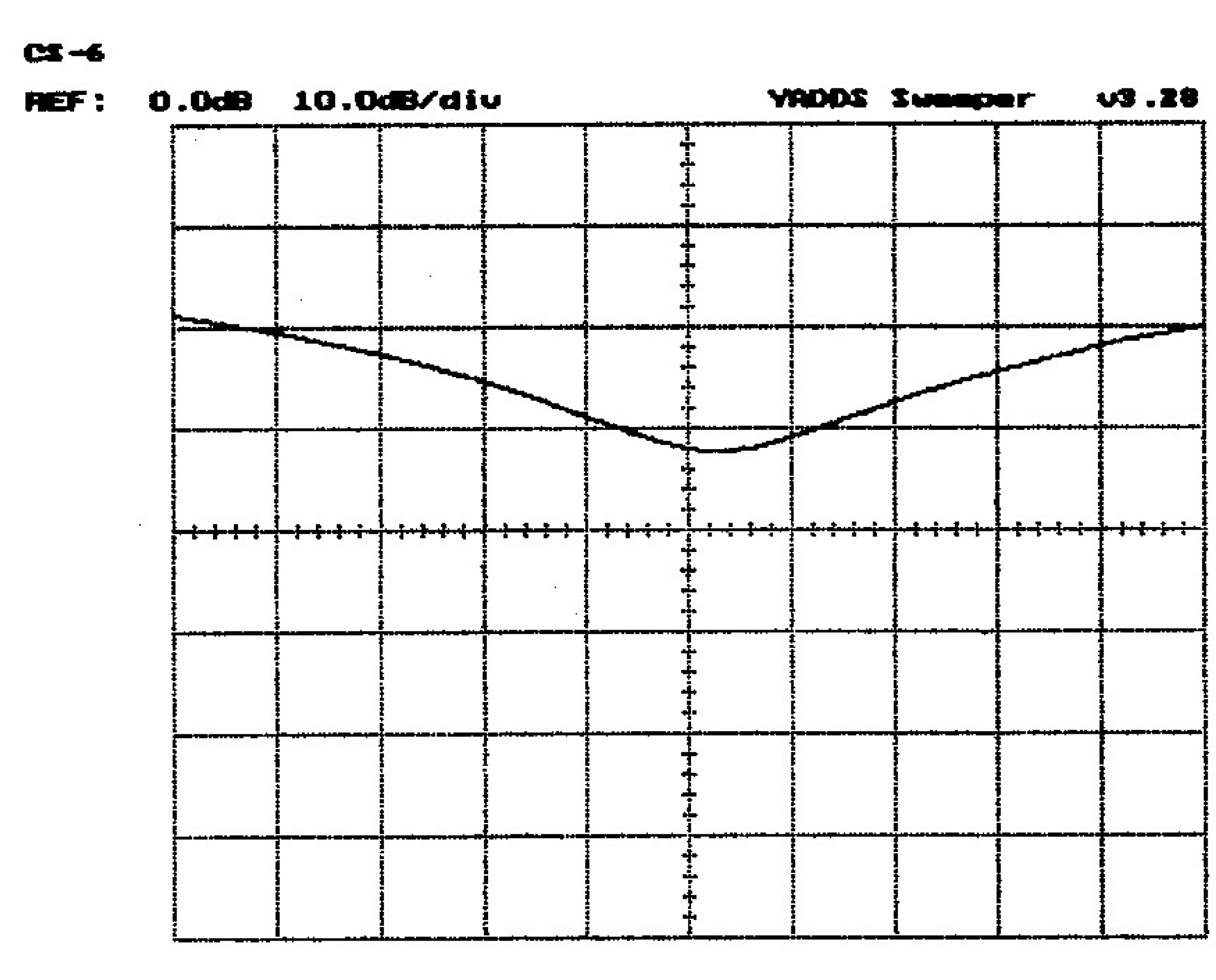
c. 1/2 wave, 14 MHz stub



d. Sub harmonic null for b.



e. 1/2 wave, 28 Mhz stub.



f. Sub harmonic null for e.

Figure 14 Frequency response for type 2 stubs.

A pair of stubs, one open and one shorted, will have equal and opposite reactance when cut to 1/8 wave or 45 degrees. If these two stubs are connected in parallel, they will form a resonant circuit. The net response when tapped onto a transmission line is similar to a ¼ wave shorted stub. The null depth will be somewhat better, however, and approaches 6 dB deeper. So an improved null can be obtained while using the same amount of cable by a simple rearrangement.

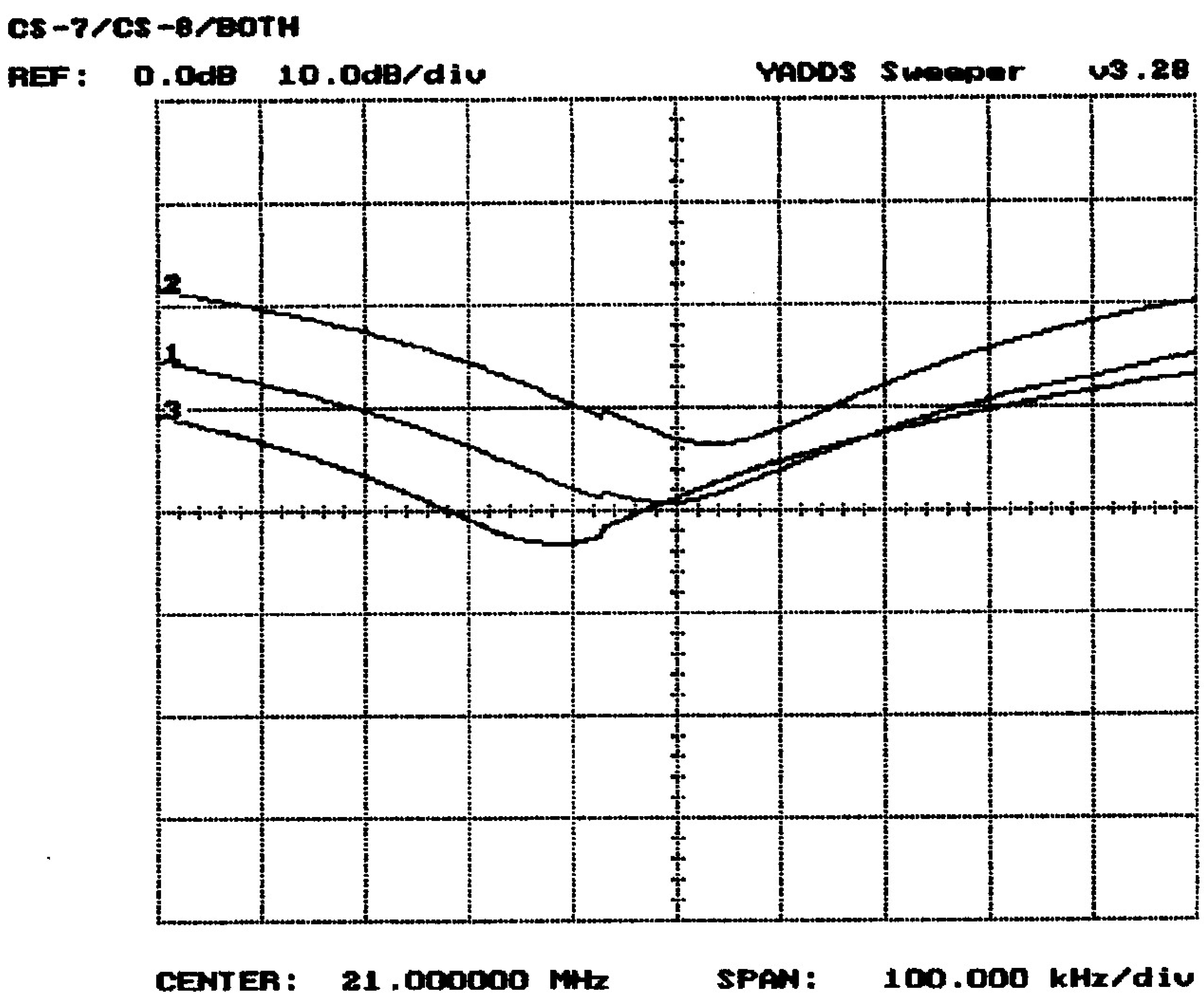
There is another benefit with 1/8 wave stubs. The shorted stub can be used as ¼ wave shorted for the next higher band. The open stub must be switched out. The number of stubs required to do an all band switching system can be minimized with this technique.

3.4.4 Type 4 - Nulling Odd Harmonics

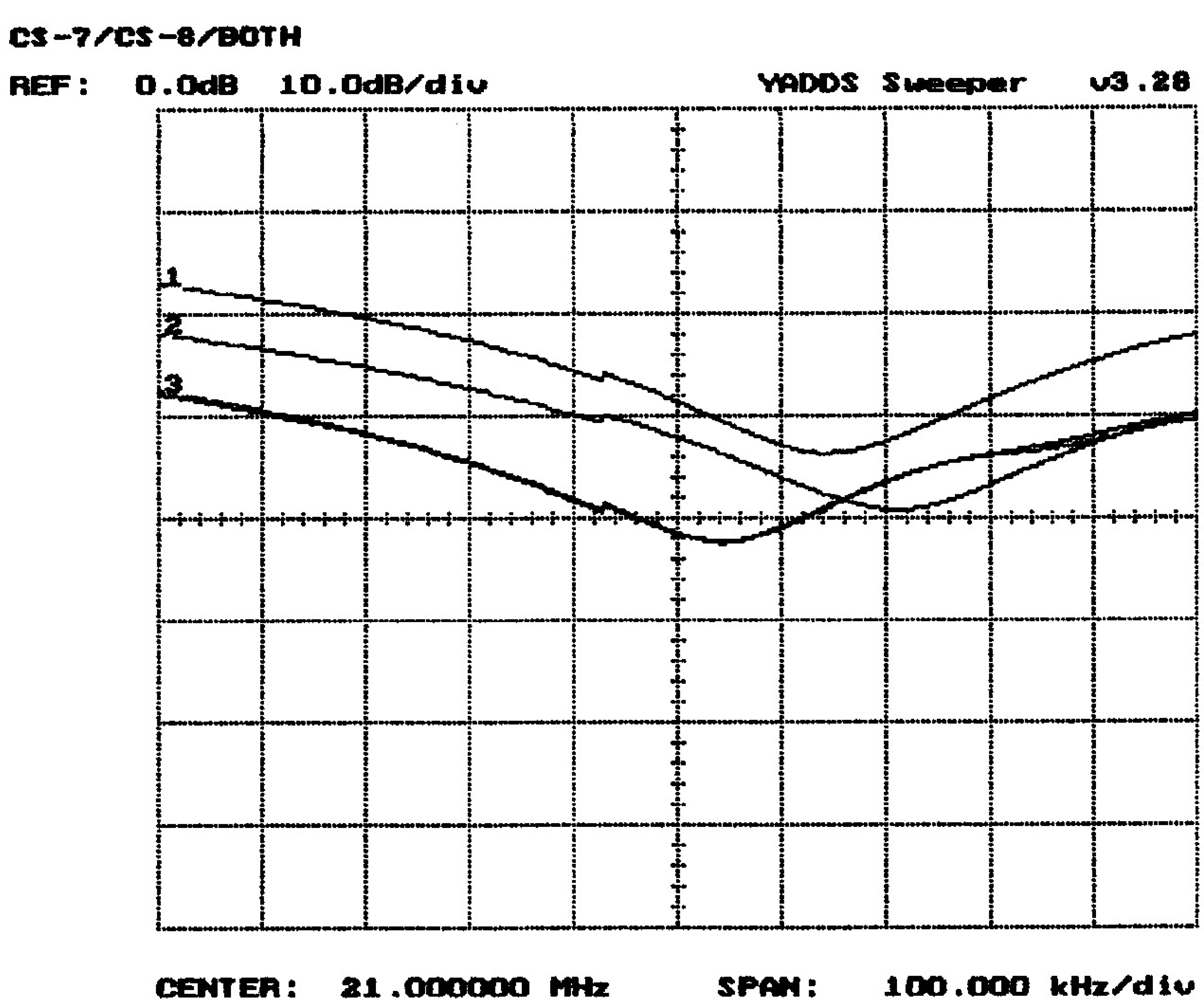
The same technique of resonating a pair of stubs can be used for another purpose. One problem that exists for the contest station is how to minimize the interference to 21 MHz from the 7 MHz transmitter. Since ¼ wave stubs only null even harmonics, they will have no effect on the 3rd. If a ¼ wave shorted stub is cut for 10.5 MHz, it will null 21 MHz. However, it will not have a good VSWR when placed across a 7 MHz transmission line. This can be fixed by paralleling an open circuit stub with the opposite reactance at 7 MHz to resonate with the shorted stub. The shorted stub is 1/6 wavelength, or 60 degrees on 7 MHz. This presents 86.6 ohms inductive reactance at its terminals. The open stub, which presents the same reactance although capacitive, is 30 electrical degrees or 1/12 wavelength. When connected together they are resonant on 7 MHz and will not change the transmission line VSWR.

What happens on 21 MHz? The shorted stub is ¼ wave on 10.5 MHz or ½ wave at 21 MHz, and will have a null on 21 MHz. The open stub is ¼ wave on 21 MHz and will also have a null on 21 MHz. Therefore, the net result is a very deep null on 21 MHz. Typically, it will exceed 40 dB for the pair of stubs.

These two stubs may be connected with a tee connector. A second tee connector then provides the input/output connections for the transmission line. The two stubs must be cut for a frequency slightly higher than the desired null frequency to compensate for the added length of the tee connector. See Figure 15a. The two stubs, 1 and 2, are cut for approximately 21,025 kHz. The resulting null, 3, moves down to 20,900 kHz. In Figure 15b the two stubs, 1 and 2, have been cut for 21,125 kHz and 21,200 kHz respectively. The overall null moves to 21,050 kHz, where it should be. Note that the shape of the overall null curve changes on the upper frequency side. If the open stub is cut any shorter, a second null forms and the desired null is reduced in depth.



a. Both cut for 21025 kHz



b. Both cut slightly short.

Figure 15 Two stubs connected together.

3.4.5 Type 5 - Non Harmonic Nulling - Null Below the Passed Frequency

An arrangement that can be used to null 7 MHz and pass 21 MHz is shown in Figure 16. Two ¼ wave 21 MHz stubs are joined with a third cable as shown, which is 0.1365 wavelength at 7 MHz. The null will be about 33 dB for one of these assemblies. If two of them are spaced ¼ wavelength at 7 MHz, the null will go down to 72 dB. This is typical for double stubs. The null is twice in dB plus 6 dB when two are spaced ¼ wave at the null frequency. The attenuation at 21 MHz for the pair will be about 0.4 dB. This is a bit high for a transmitting system, but is not excessive for receiving. The purpose of the assembly is to protect a 21 MHz receiver from 7 MHz energy and it would have little benefit on the output of a transmitter. For other ratios of nulled to passed frequencies the following calculations can be used.

$Fp > Fn$

$L1 = L2 = 163.5/Fp$ *feet (1/4 WL at Fp)*

In electrical degrees at Fn, $\theta 1 = \theta 2 = 90(Fn/Fp)$

L2 and L3 must add enough length to make an open circuited ¼ WL at Fn.

The required additional electrical length is:

$\theta e = 90 - \theta 1$

This is the result of L2 and L3 in parallel

L3 in electrical degrees = $\theta 3 = Atan(-2\cot 2\theta e)$

L3 in feet = $1.817(\theta 3 / Fn)$

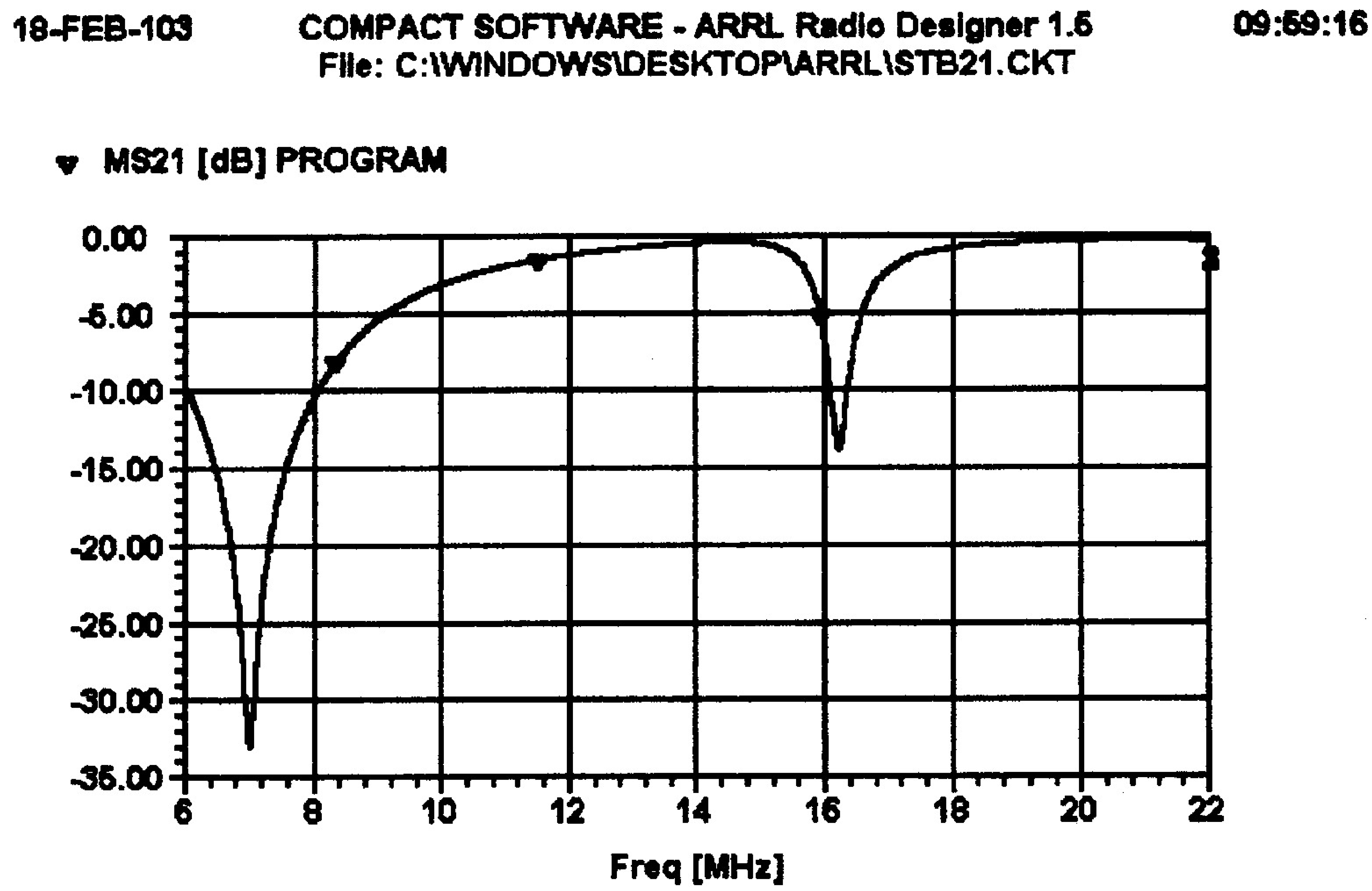


Figure 16 The type 5 stub arrangement.

3.4.6 Type 6 - Non Harmonic Nulling - Null Above the Passed Frequency

The approach used for Type 4 stubs could be extended to non harmonically related interfering signals with some reduction in null depth. This is because both stubs would not be resonant on the interfering signal. As an example, let's design a pair of stubs to reject 18.0 MHz and to be used on a 7.0 MHz station. We start with a type 1 shorted stub for 9.0 MHz. This stub would be 7.0/9.0 x 90 degrees on 7 MHz, or 70 degrees. The inductive reactance is 50 x tan 70 = 137.37 ohms. To minimize loss and VSWR on 7 MHz we need an equal capacitive reactance to resonate with this inductance. A short, open circuit compensating stub supplies the capacitive reactance. The open circuit stub would have to be 90 – 70 = 20 degrees to have the same (but opposite sign) reactance. The actual lengths would be:

Shorted stub = (70/360) x (983.6/7) x 0.665 = 18' 2"

Open stub = (20/360) x (983.6/7) x 0.665 = 5' 2.3"

We could expect a null depth of 25 to 30 dB with this arrangement.

The resulting characteristics are shown in the ARD plot, Figure 17. The insertion loss is very low at 0.08 dB. Null depth is 28 dB.

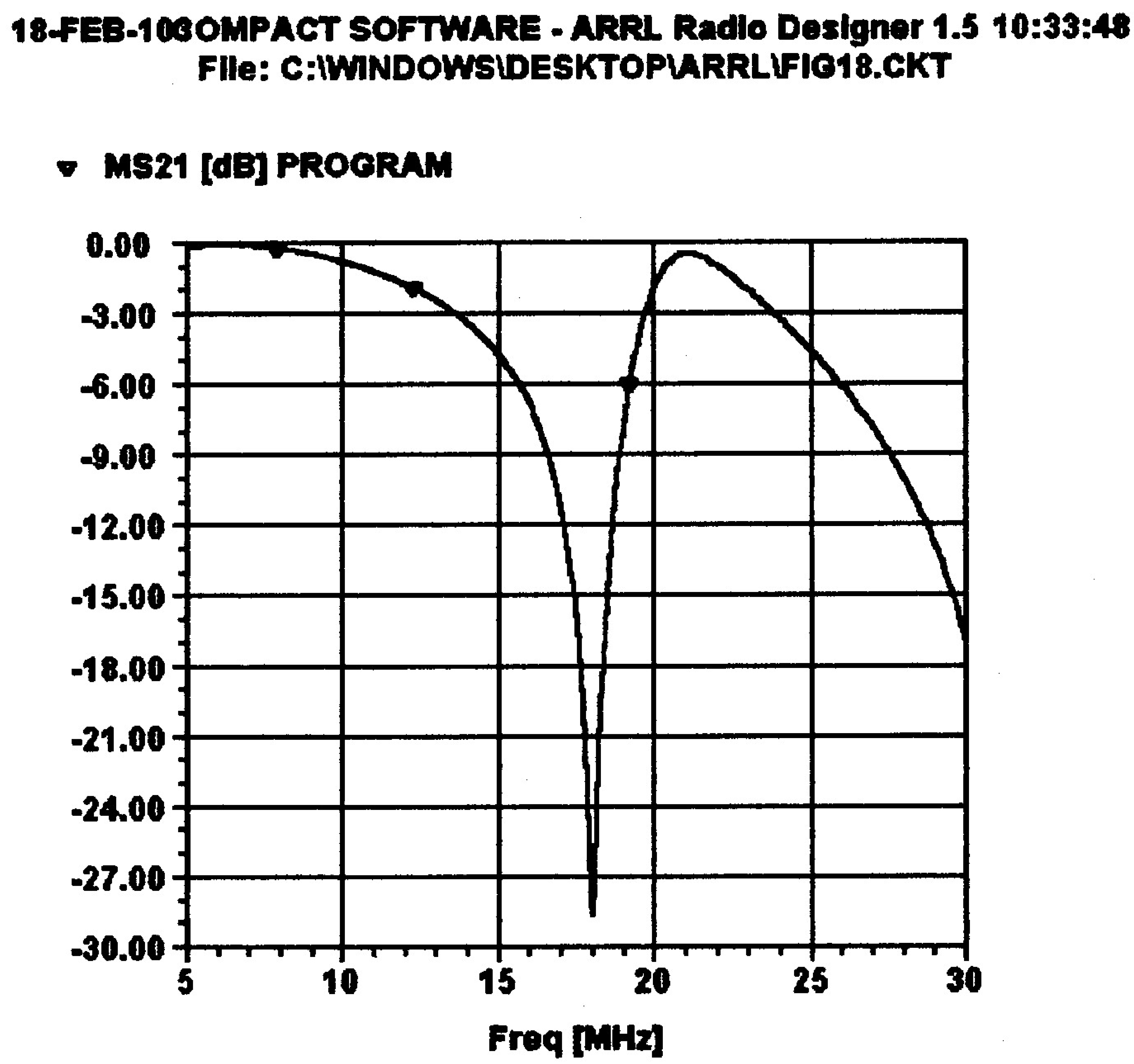


Figure 17 Type 6 stub response.

3.4.7 Type 7 - Non Harmonic Nulling Variation - Null Below the Passed Frequency

Suppose we want to null 7 MHz and pass 18 MHz. Here we can start with a 1/2 wave open stub, Type 2, at twice 7 MHz to provide the null. The wavelength of this stub at 18 MHz would be 18.0/14.0 x 180 degrees = 231.4 degrees. The reactance is 50 COT 231.4 = 39.87 ohms. From Table 11 we determine that the reactance is capacitive for an open stub between ½ and ¾ wavelength. Therefore, we need an inductive stub to compensate. Its length in degrees can be determined as follows:

50 tan le = 39.87

le = 38.57 degrees at 18 MHz.

And the physical length = (38.57/360) x (983.6/18.0) x 0.665 = 3' 10.7"

The resulting plot is shown in Figure 18. Insertion loss is a bit high at –0.42 dB. The null depth is 30 dB. There is also a –25 dB null at 21 MHz. The proximity of the 21 MHz null is responsible for the high insertion loss.

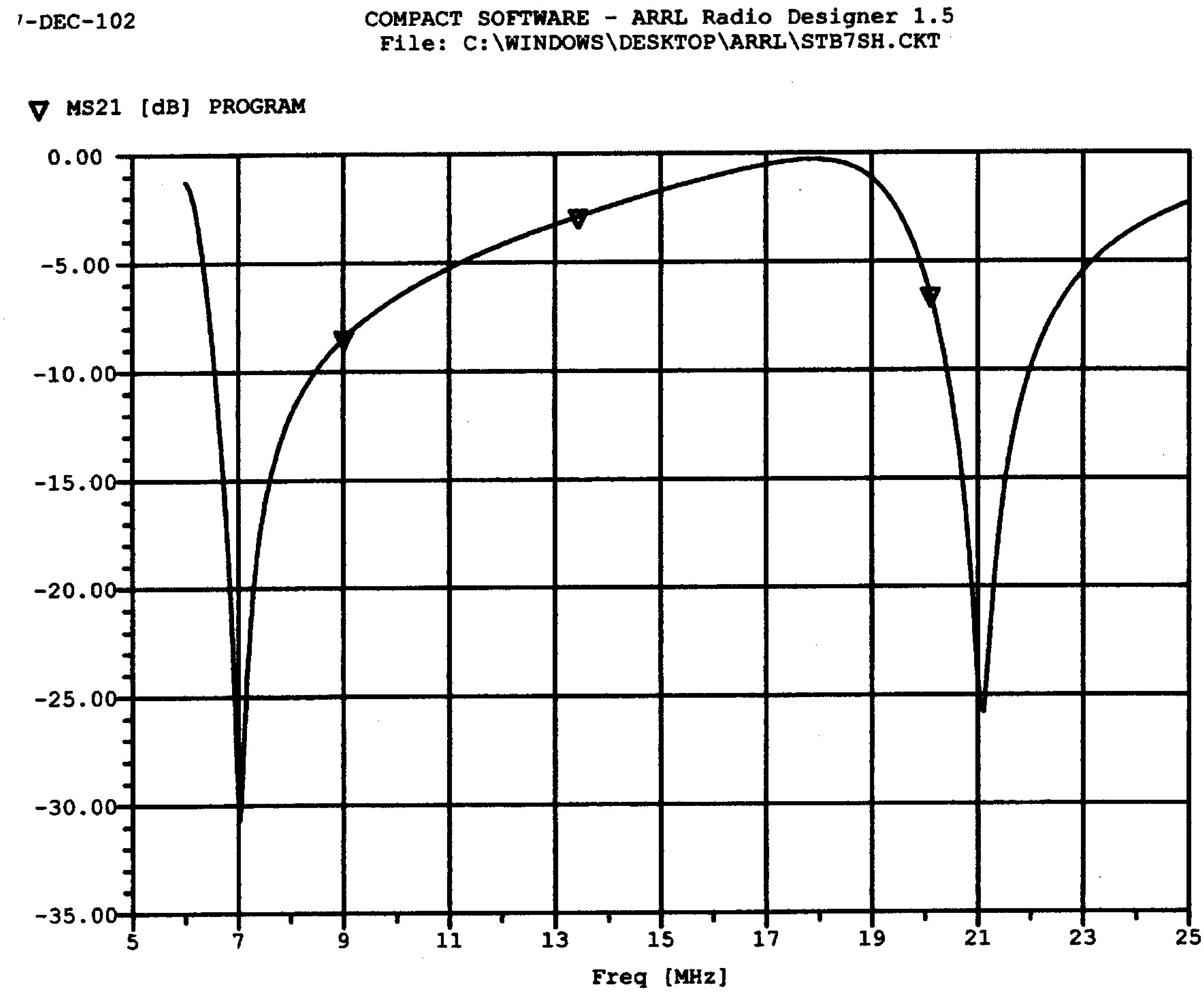


Figure 18 Type 7 stub response.

3.4.8 Type 8 - Nulling Above and Below the Operating Frequency

If a one wavelength open circuit stub has its far end connected back to its beginning, we get an interesting result. At the design frequency the input energy splits, and half goes down the added stub where it is delayed by one full cycle. It returns to the starting point in phase and adds to the input energy, so there is no net attenuation. However, at one half the design frequency the wave returns out of phase to null the input energy. At three times the design frequency the wave also returns out of phase and creates a null. This type of stub is useful for passing 14 and 28 MHz while nulling 7 and 21 MHz.

3.5 Effects of Various Cables

Figure 19 shows attenuation plots for three ¼ wave, shorted stubs made with RG8x. There is 4 to 6 dB less attenuation when stubs are made from RG8x as compared to RG-213. When space or weight is a primary consideration, RG8x does a decent job of attenuating harmonics. At the lower end of the HF bands

RG8x will stand full legal power. It will warm up when used on the higher bands. To prevent overheating, the stubs should not be coiled up too tightly or stuffed into a small space. A set of double stubs was made up for use at HC8N with RG8x. Since I was carrying them to the Galapagos Islands, they were packaged into several small aluminum chasses with coax connectors. Each band had a dedicated stub assembly. They worked fine for the first few contests, but after a year or more of use, some shorts developed in the coax. They got a bit warm, even with the 1000 to 1200 Watt power level in use at the station, and the center conductor drifted over to the shield in the soft foam insulation.

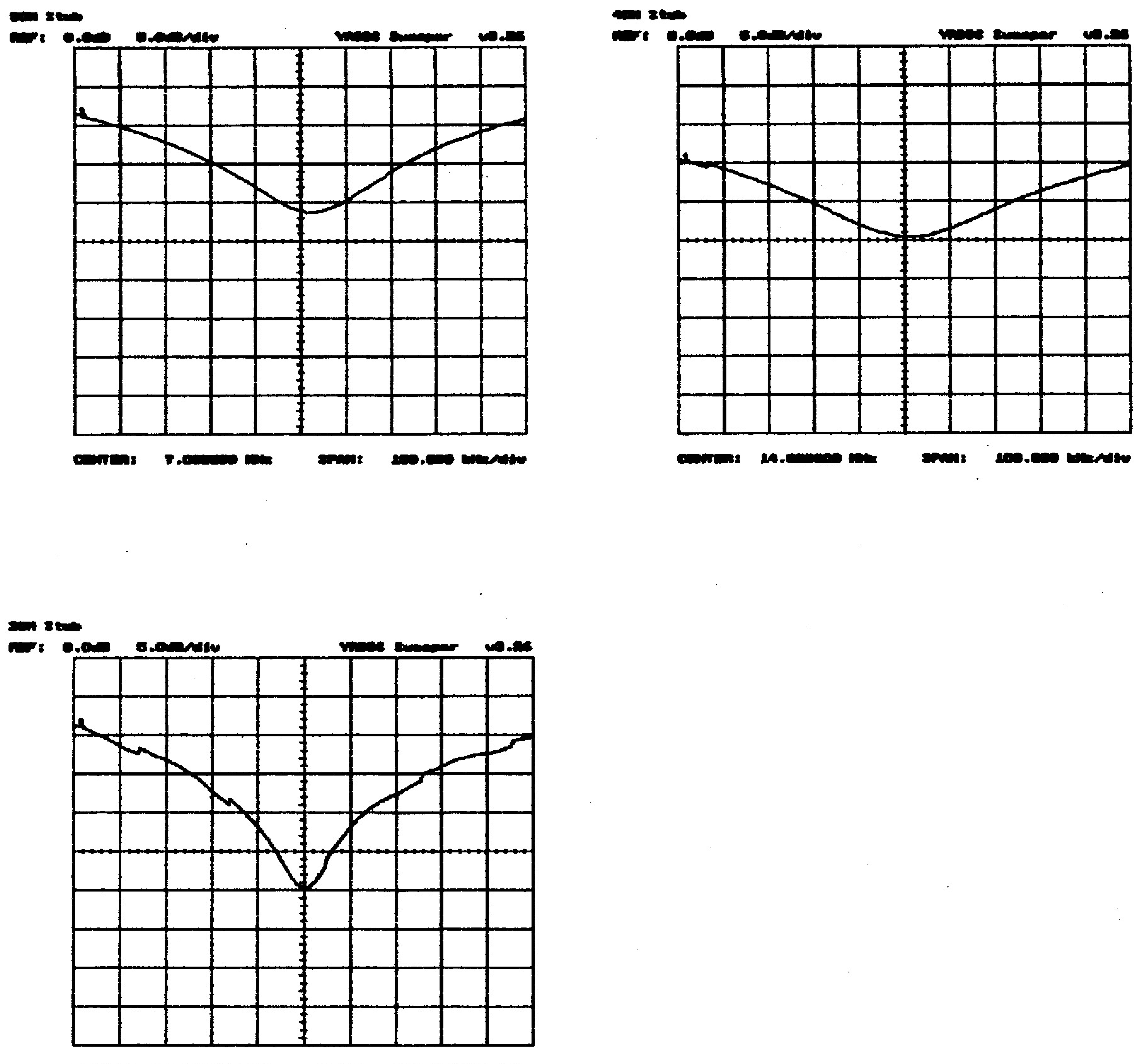


Figure 19 Stubs made from RG-8x. Vertical scale = 5 dB/division.

Figure 20 shows the 28 MHz null for a ¼ wave shorted 14 MHz stub made from LMR400. This is a good quality, foam dielectric cable about the same size as RG-213. It fits perfectly into the UHF series connectors. Note the null attenuation at –32 dB compared to RG-213 in Figure 11f at –34 dB.

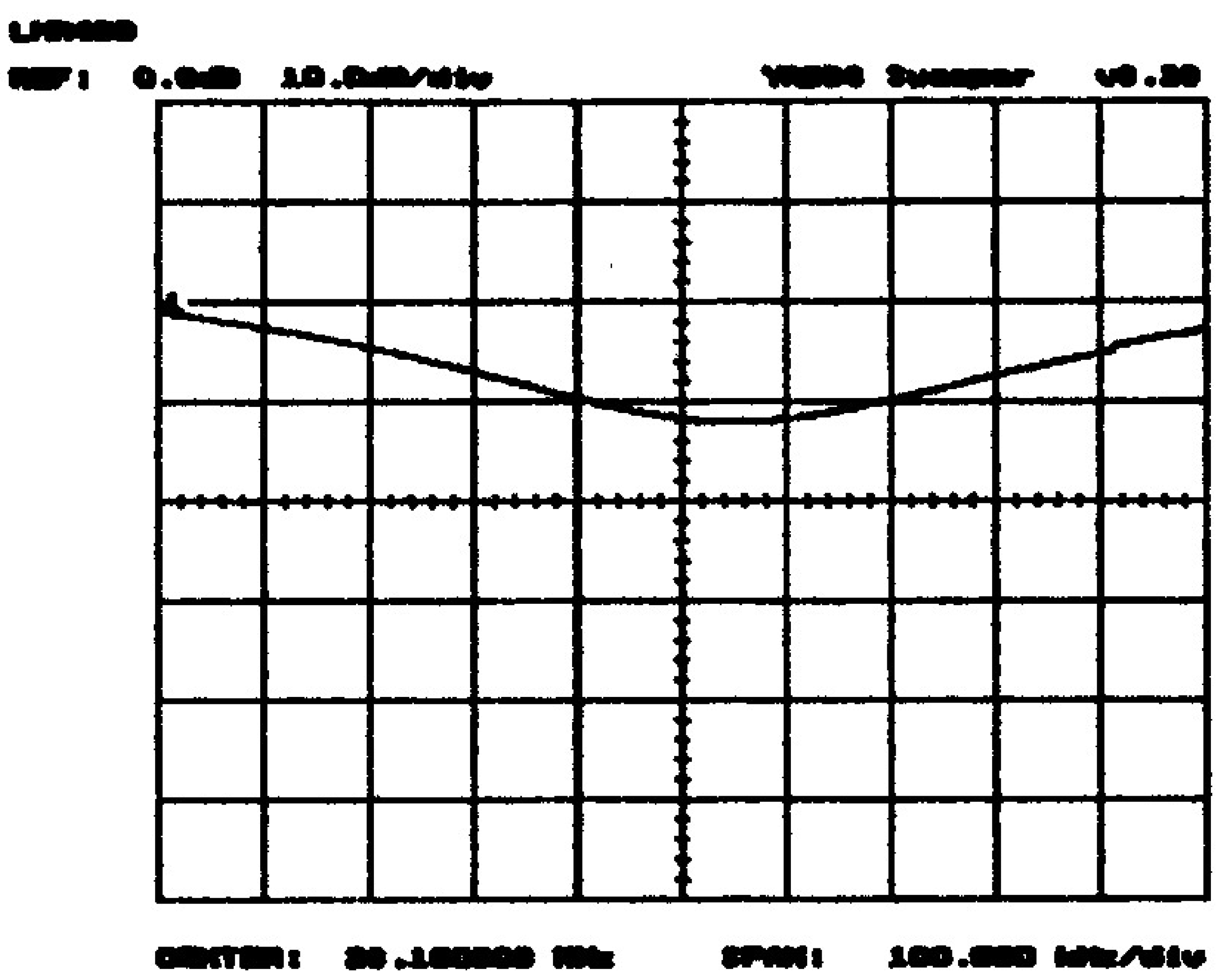


Figure 20 Stub made from LMR400.

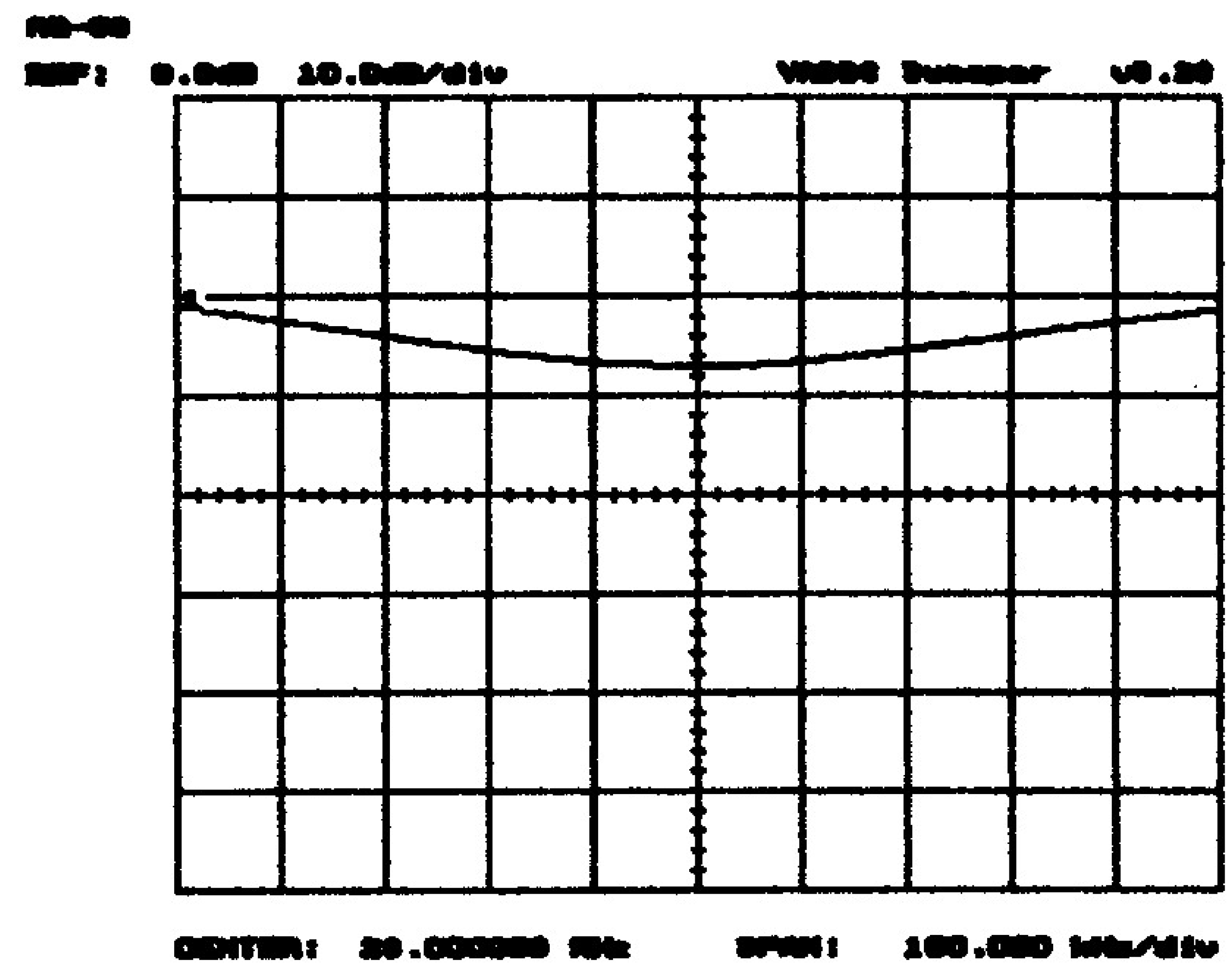


Figure 21 Stub made from RG58.

Figure 21 shows a similar stub made from RG-58. It has a null depth of -27 dB, or about 3 dB less than RG-8x. It may take coiling up into small spaces better than RG-8x due to its solid inner insulation.

3.6 Using Multiple Stubs

There are a number of different ways to increase the attenuation provided by stubs. The simplest way is to put two stubs in parallel on a tee connector, but this is not very effective, as it simply adds 6 dB to the null by halving the effective shunt resistance. There are some other ways to use two stubs that will double the attenuation of one stub in dB and also add another 6 dB. Thus if a stub has 27 dB of attenuation it is possible to get 60 dB by using two of them coupled with a line or a lumped element.

3.6.1 Type 1 Stubs Coupled with a Coaxial Line

Figure 22 shows the general method of coupling two Type 1, ¼ wave shorted stubs. As CC, the coupling cable, is increased in length from zero, the additional attenuation increases rapidly from 6 dB upwards. Interesting things occur with the null depths at the various harmonics as CC is varied.

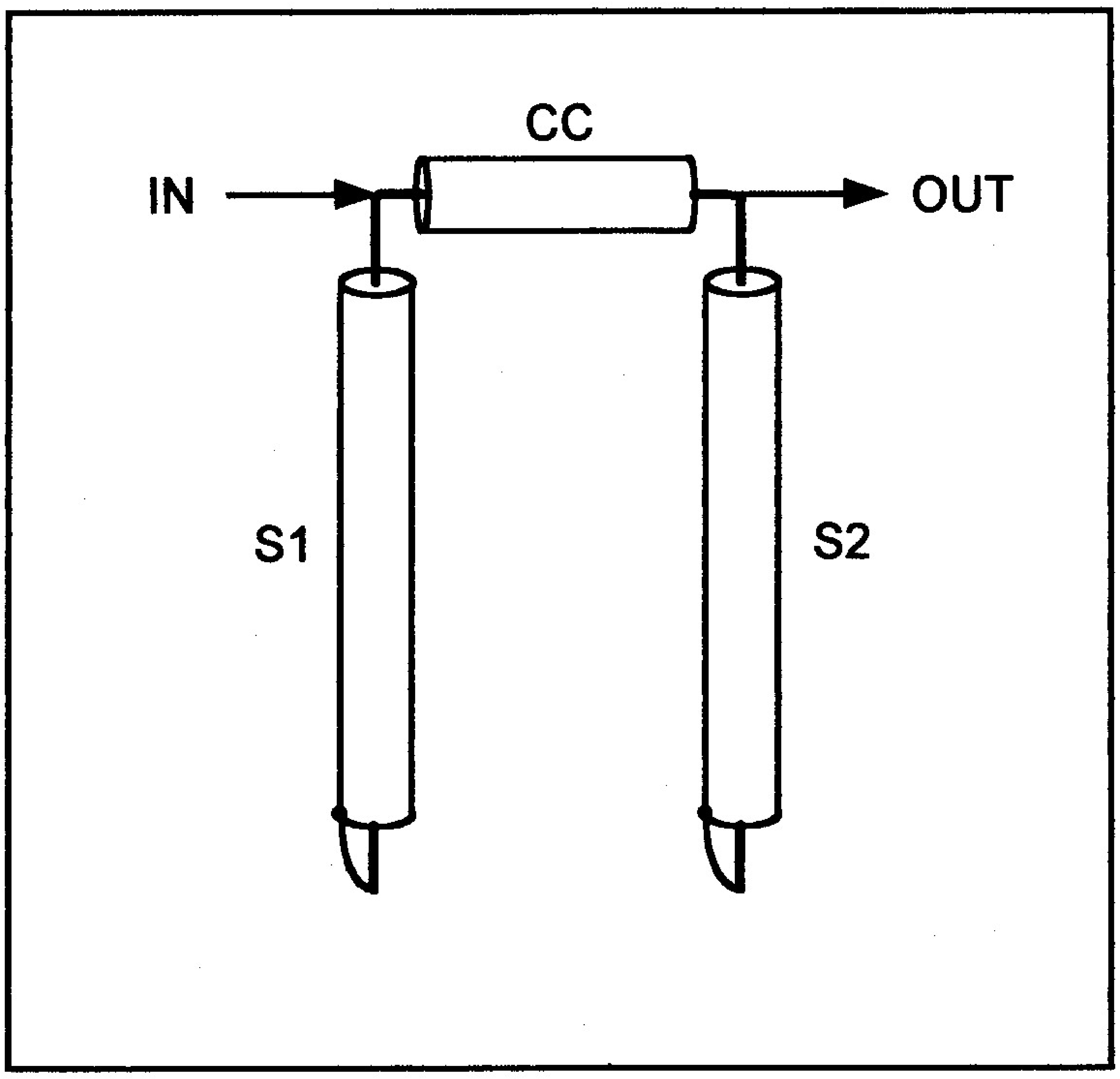


Figure 22 Double stub arrangement.

Table 12, below, shows what happens. CC is measured in wavelengths at the fundamental frequency. The values in the table were obtained by simulating a pair of 80 meter, ¼ wave shorted stubs made from RG-213U. So the 2F is 7MHz, 4F=14MHz, 6F=21MHz and 8F=28MHz.

Table 12 Effect of varying the coupling cable length.

CC Length	2F	4F	6F	8F
1/24wl	-70dB	-74	-80	-74
1/16	-73	-76	-80	-42
1/6	-74	-75	-78	-75
1/8	-75	-43	-80	-43

Conventional wisdom has always said the coupler should be ¼ wavelength at the second harmonic to minimize that component. That would be 1/8 wavelength at the fundamental, of course. We can see that the second harmonic is minimized with that length, but let's look at the other null depths. At 4F and 8F the null is just -43dB, whereas with a 1/24 or 1/6 wavelength coupler they are down 74 or 75 dB. Therefore, we can save some coax and improve the performance of coupled stubs by a large margin if we use 1/24 or 1/6 wavelength couplers. The actual null depths obtained in practice may be a bit less than those shown in the table, but the relative depths will be similar.

Figure 23 shows actual measurements on a pair of ¼ wave shorted 40-meter stubs with several coupling cable lengths. Each graph shows a single stub and a pair of stubs. The top three graphs are centrered at 14 MHz and the lower three are centered at 28 MHz.

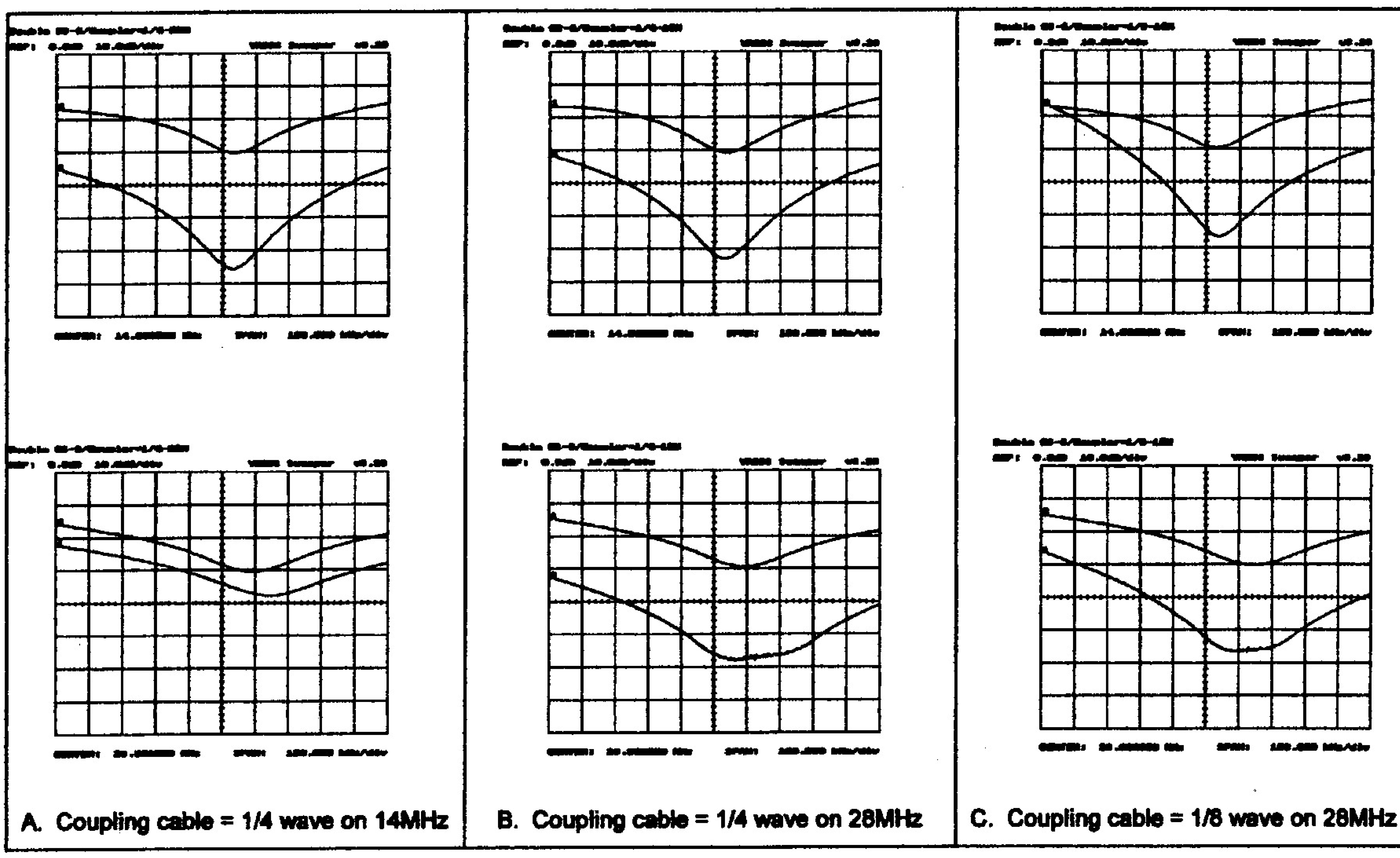


Figure 23 Null depth variations with changes in coupling cable length.

Table 13, below, summarizes.

Table 13 Effects of varying coupling cable length.

CC Length	14 MHz	28 MHz
1/8 wl on 7MHz	-66	-38dB
1/16 wl	-63	-58
1/32 wl	-57	-56

This clearly shows that we want to use 1/16 wave couplers (1/8 on the second harmonic) to minimize the total harmonic radiation for 2F and 4F. In this case the higher harmonics above 4F are not important.

For 80 meter assemblies, we might use 1/32 wavelength to minimize 2F through 8F total harmonic energy.

3.6.2 Type 2 Stubs Coupled with a Coaxial Line

Half wave open stubs for sub harmonic nulling can also be coupled for greater attenuation. In this case the coupler should be ¼ wave on the sub harmonic. Figure 24 shows measured curves for a pair of 10 meter RG 213 stubs coupled with a ¼ wavelength 20 meter line. The single stub shows 36 dB attenuation while the double shows 78 dB. It also fits the approximation of 2x dB plus 6 dB for a single stub.

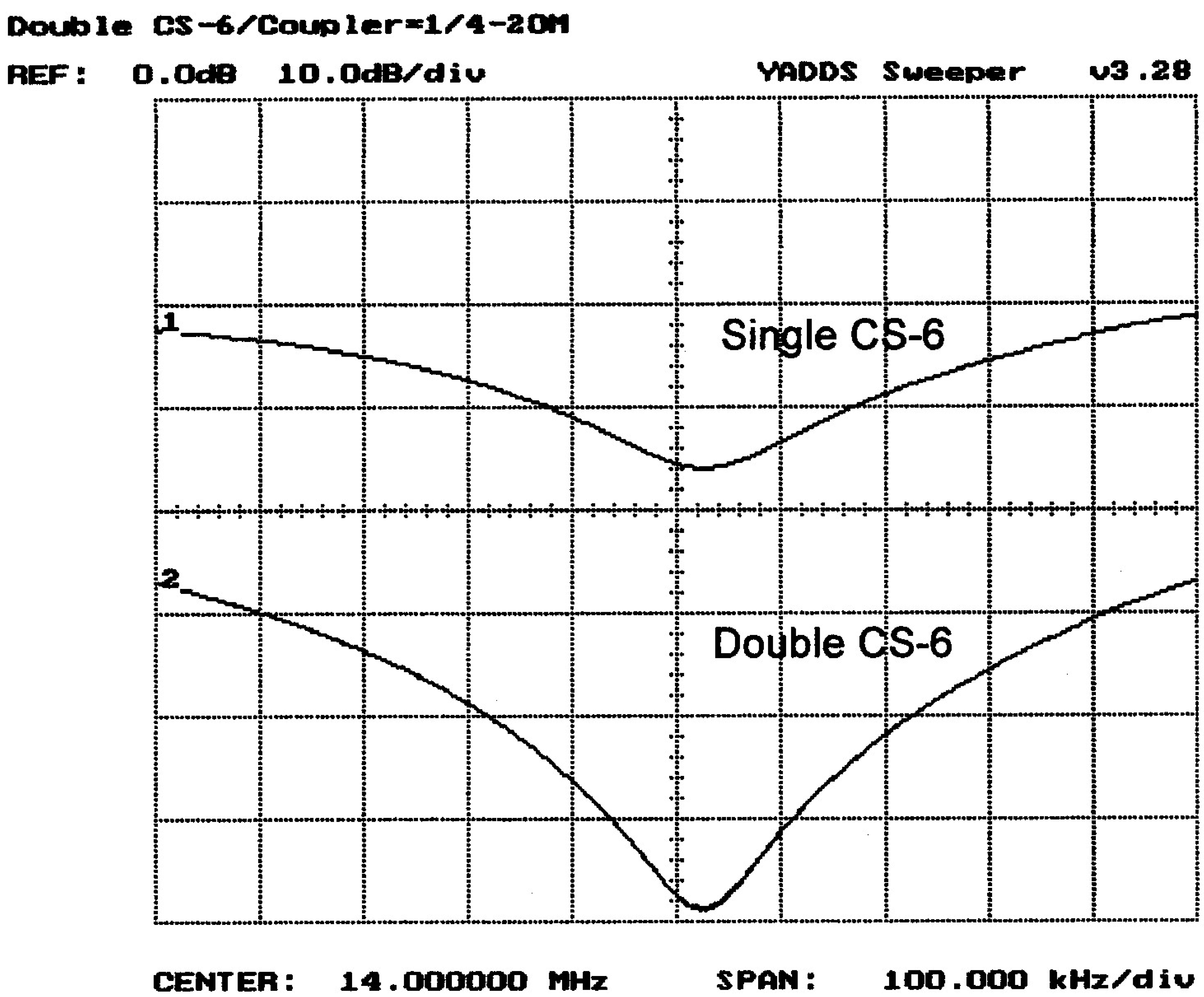


Figure 24 A pair of ½ wave open stubs coupled with a ¼ wave sub harmonic line.

3.6.3 Combinations for SSB and CW

Coupled stubs can be cut for different frequencies to widen the null. The obvious use for this is to cover both the SSB and CW bands. This is particularly true for 40, 20 and 15 meters where the sub bands are not that far apart. On 80 and 10 meters the result will be a double null with some reduced attenuation in between. When cutting these stubs it is best to cut one first, then assemble the coupler and second stub for trimming. That is, don't cut the stubs one at a time and then assemble, as there is some interaction when they are coupled. Figure 25 shows a set of RG-213 stubs cut for 40 meters, which has flat attenuation from 7000 to 7150. There is a loss of about 8 dB for the low CW end in the stagger tuning, but the null is much wider. Curve 1 is a single stub. Curve 2 is 2 stubs cut for CW and Curve 3 shows one cut for CW and one cut for low SSB. Figure 26 shows a pair of CS-5s stagger tuned to cover 28 to 28.5 MHz. Note the almost 60 dB attenuation over the band of interest.

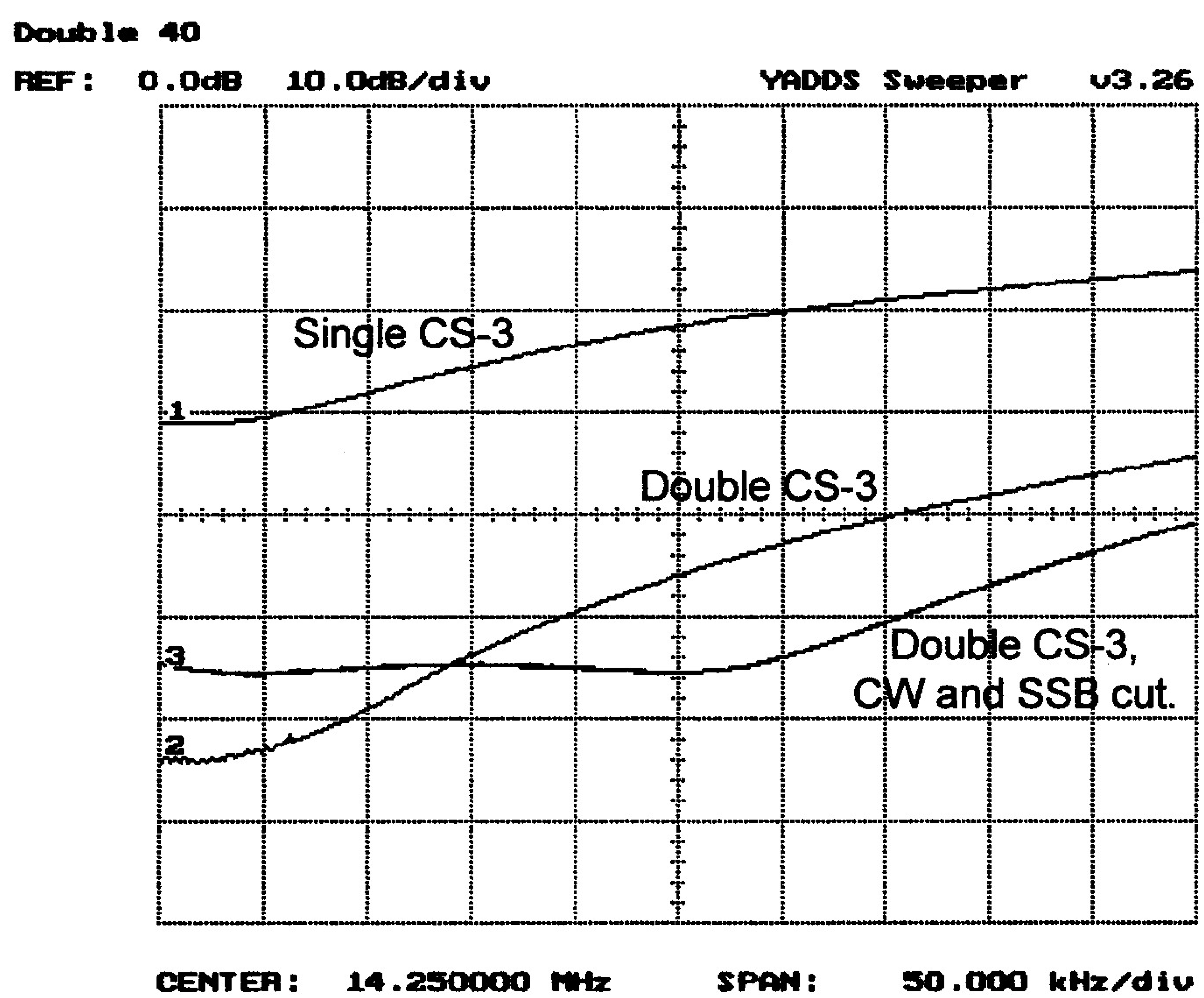


Figure 25 Double ¼ wave stubs for 7 MHz.

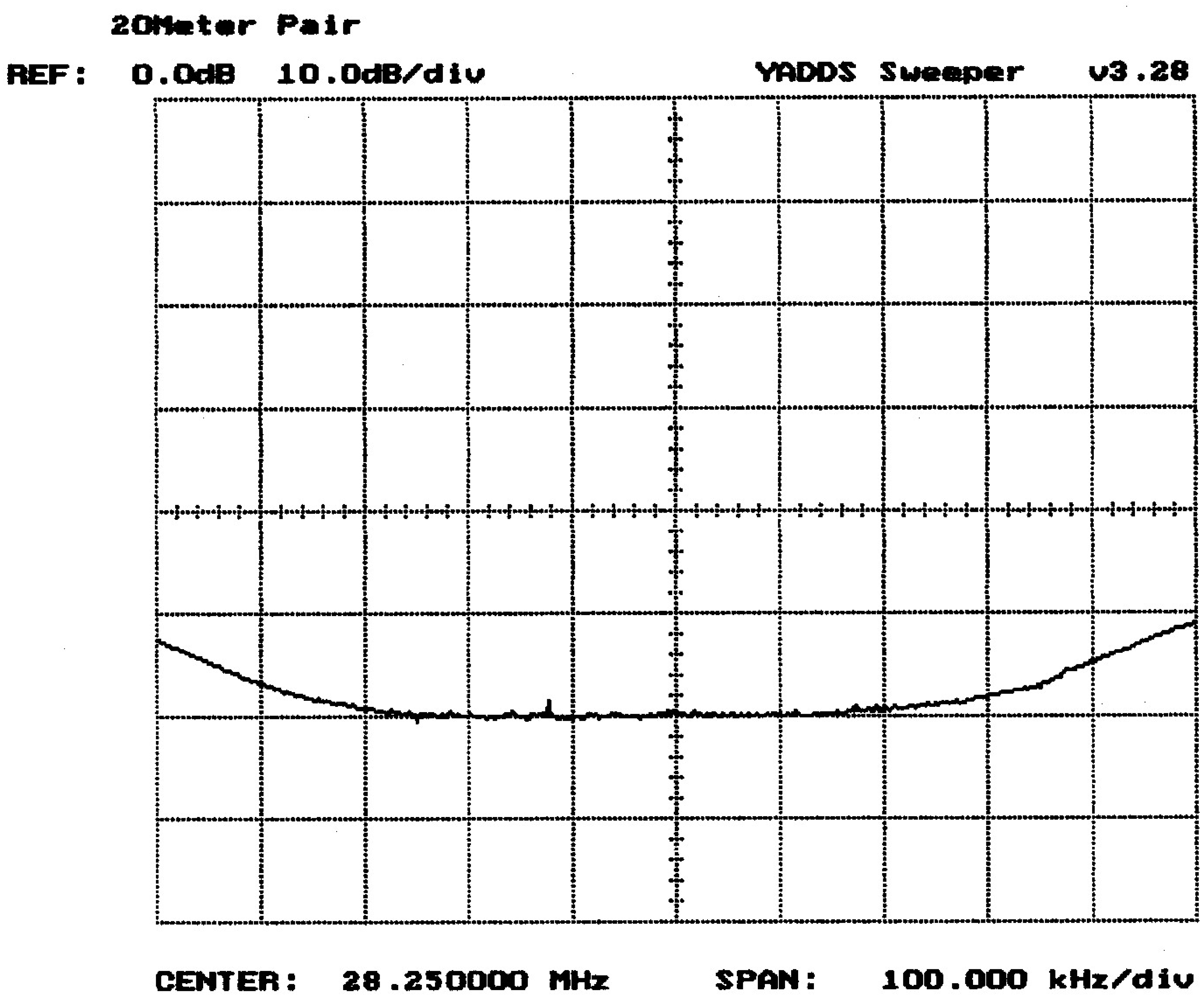


Figure 26 A pair of ¼ wave 14 MHz stubs , one cut for CW and one cut for SSB.

3.6.4 Connecting Multiple Stubs

Stubs for various harmonics and sub harmonics can be connected together with tee connectors. The way they are connected can have some effect on how they perform. The best connecting method is one that has no common portion of the transmission line shared between stubs. Put another way, stubs should be connected directly to the transmission line between line and load, and not to another stub. This is best illustrated as shown in Figure 27. Figure 27a shows two stubs attached to a transmission line going from an amplifier to an antenna. Each stub connects directly to the transmission path. In Figure 27b, the same number of adapters is used, but there is a common path between the stubs to the transmission path. This common path can cause interaction between the stubs. For example: stub A is cut to null 28,025 kHz and stub B is cut to null 28,550 kHz. When the two are connected as in Figure 27a, they function as designed. When connected as in Figure 27b, the nulls are displaced.

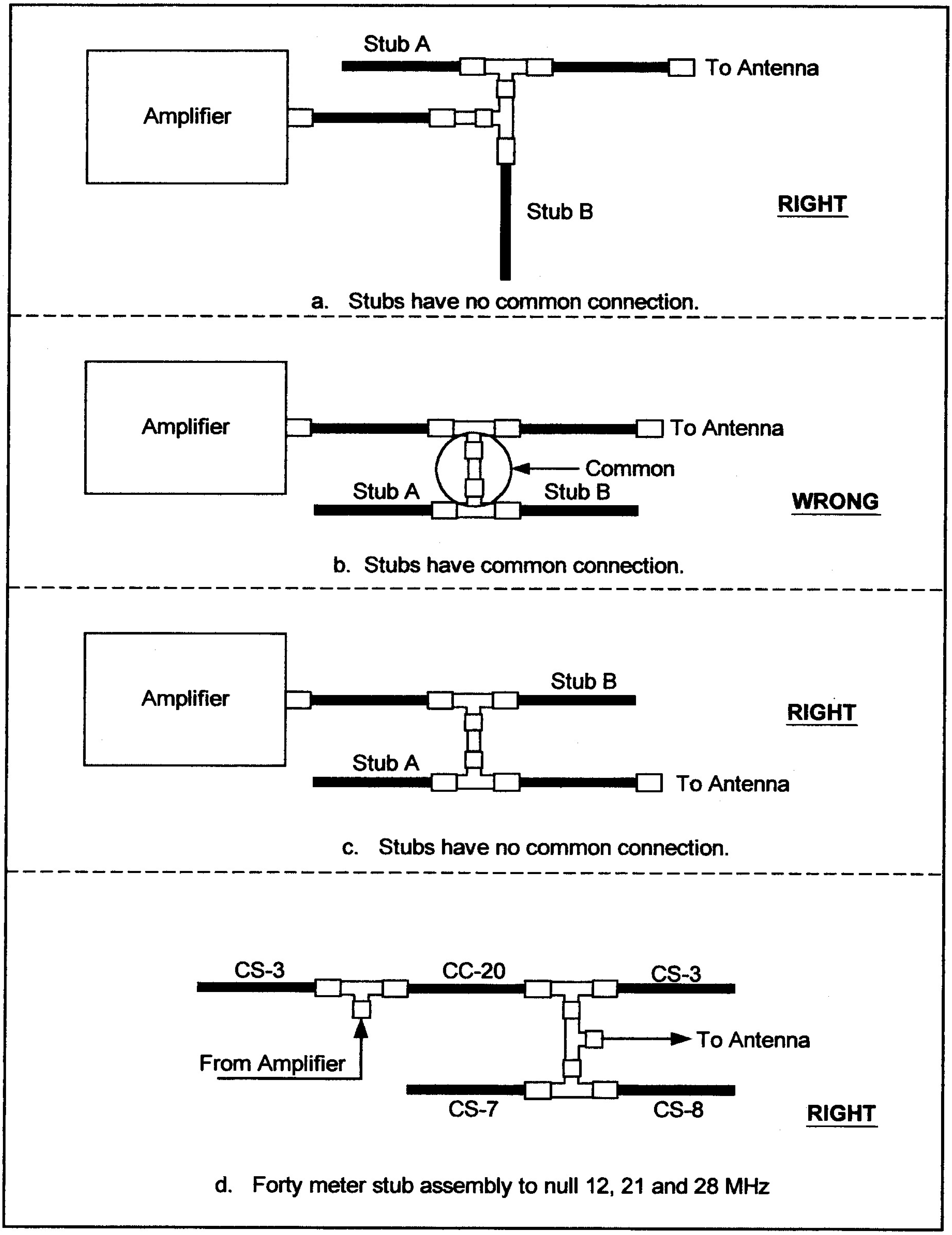


Figure 27 Various ways to connect a pair of stubs.

Figure 28 shows a spectrum analyzer sweep of two CS-5 stubs cut as described above. The actual frequencies came out closer to 28,000 and 28,450 kHz. When connected as shown in Figure 27a, there is some interaction, but the nulls stay on the frequencies for which they were cut. The lower null is reduced a few dB and the upper null is increased a similar amount. See Curve 2 in Figure 28. If the length of line connecting the two together is increased from an inch or two to a few feet, the nulls will merge and become some 50 dB deep while staying at the original frequencies, as shown in the section on combinations for SSB and CW.

The connection shown in Figure 27b results in the shifting of both nulls in a lower frequency direction. In this case, the lower null is increased while the upper is reduced. Any increase in the length of common coupling between the stubs will lower both null frequencies. See Curve 1 in Figure 28. Note that the nulls are shifted almost 400 kHz lower than the cut frequencies. Simply swapping positions of the antenna line and one of the stubs will remove the common connection, as shown in Figure 27c. This connection has the same frequency response as Figure 27a.

This basic arrangement of two stubs is used as an illustration of interaction between stubs. Two stubs with nulls very close together were chosen for this example. It becomes more critical when connecting multiple stubs. The more tees and barrels required for connections, the more confusing it becomes to avoid the common connection between stubs. Figure 27d shows a 40 meter, single band setup which might be used for a multiple transmitter contest station. The pair of CS-3s produces nulls at 14 and 28 MHz for the 2nd and 4th harmonics, while the CS7/8 null the 3rd harmonic at 21 MHz. Note the connection methods for eliminating common sections between stubs.

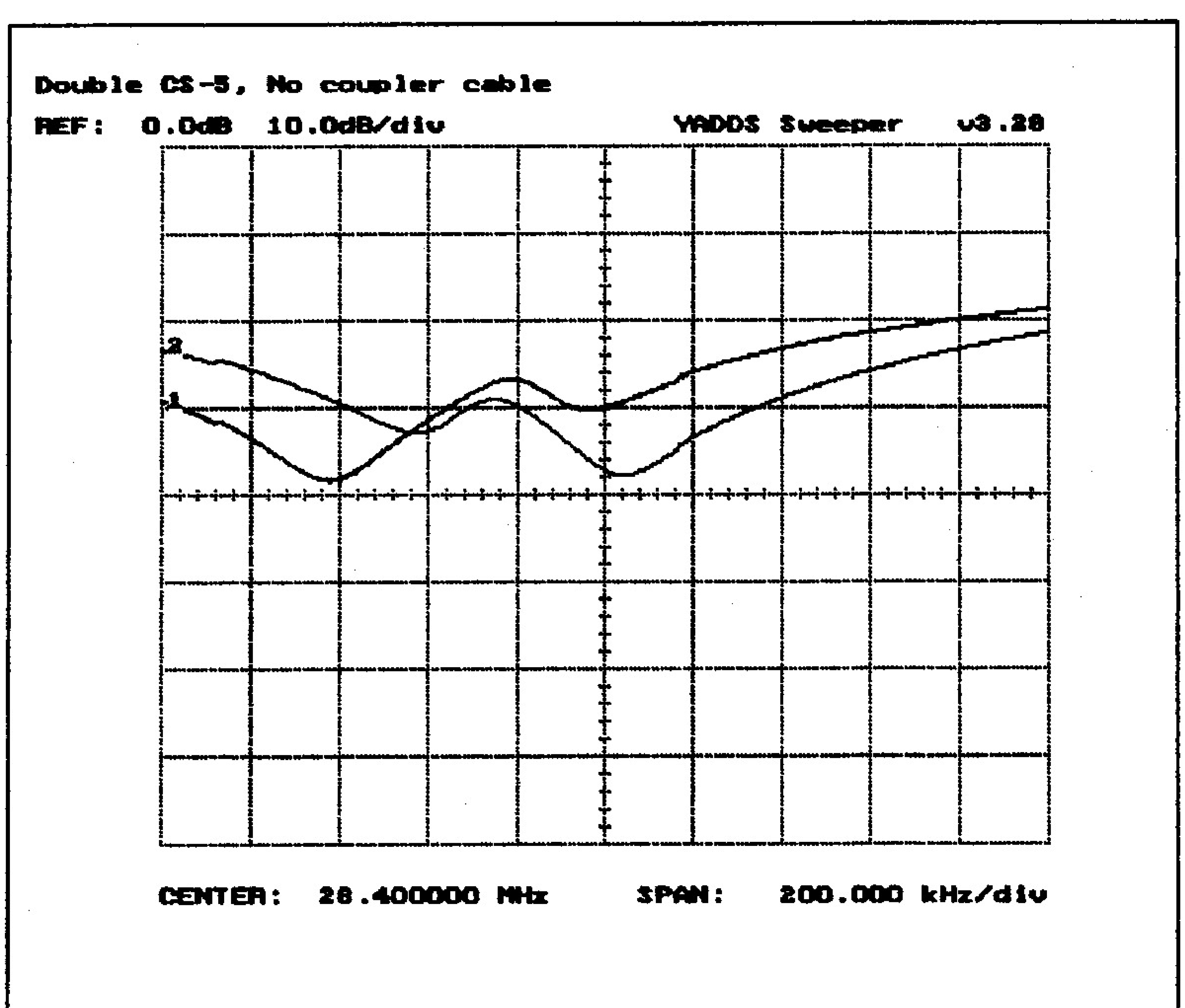


Figure 28 Two stubs connected as in Figure 27b.

3.7 Losses and VSWR

If stubs are cut accurately for the operating frequency range, the loss will be very low. Loss is so low, in fact, that my computerized test equipment cannot measure it very well. The older spectrum analyzer, which does not have a computer interface, has no problem with this low loss. A pair of CS-5s cut for 20 meter SSB and CW service show a loss of 0.08 dB over the 14 to 14.35 MHz band. The range for less than ½ dB loss extends from 11 to 15 MHz.

The VSWR at the operating frequency is 1.00. The frequency range for the VSWR to be less than 1.10 is 13.1 to 14.9 MHz.

Properly cut stubs have essentially zero effect at the operating frequency.

3.8 Band switching stubs

When one transmitter is to be used on more than one band, it becomes necessary to switch the stubs. There are many ways to do this. In Figure 29 the stubs are selected separately from the antennas. One advantage here is that multiband antennas are easy to accommodate. The bandswitching stub assembly could be located in the shack while the antenna switch is at the tower.

When a relay or manual switch is used to select stubs as shown, the stub length must be adjusted for the equivalent length in the switch. This is best done with the stub attached to the switch while making the final cut of cable.

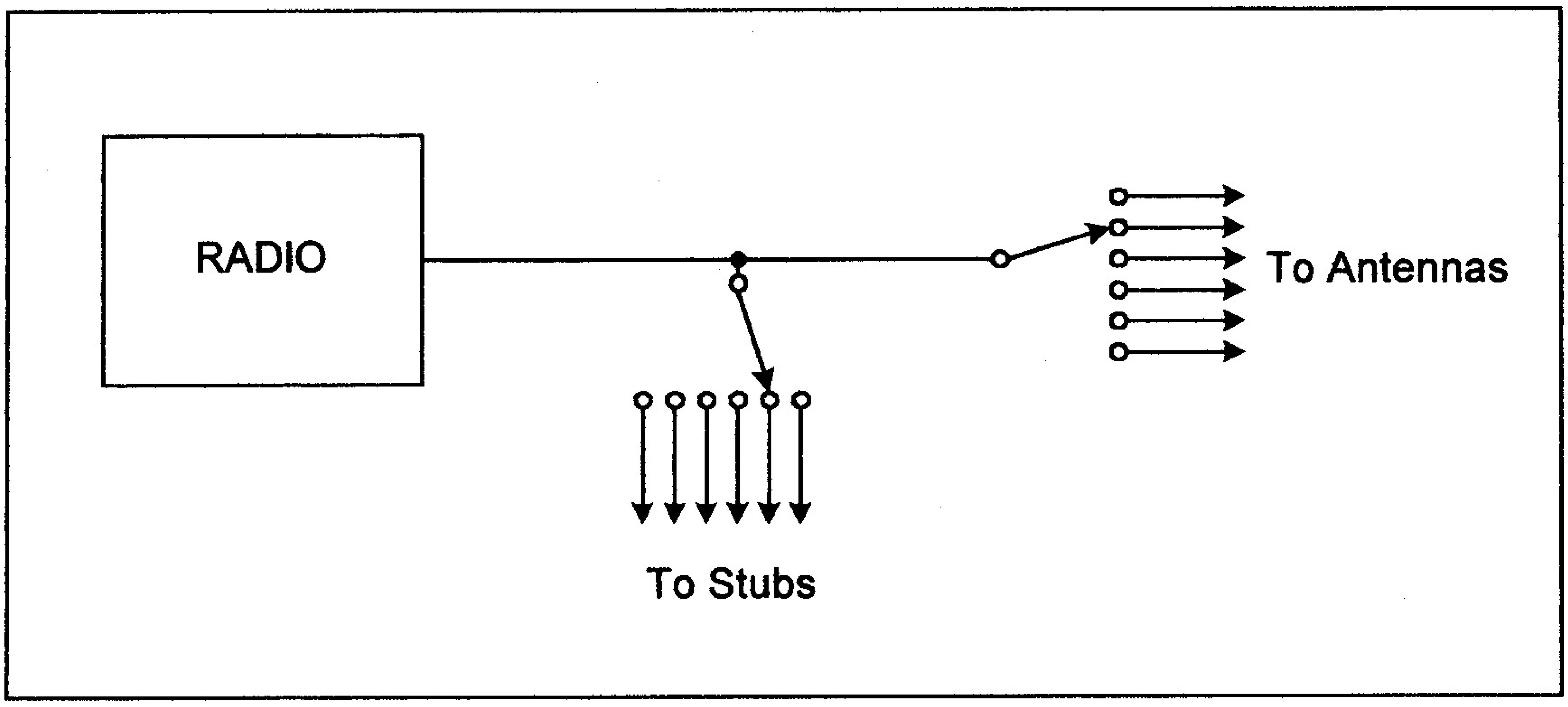


Figure 29 Separate switches for stubs and antennas.

In Figure 30, the stubs are placed on the coax lines going out to monoband antennas after the antenna selector switch. The switch could be in the shack or out at the tower and remotely controlled.

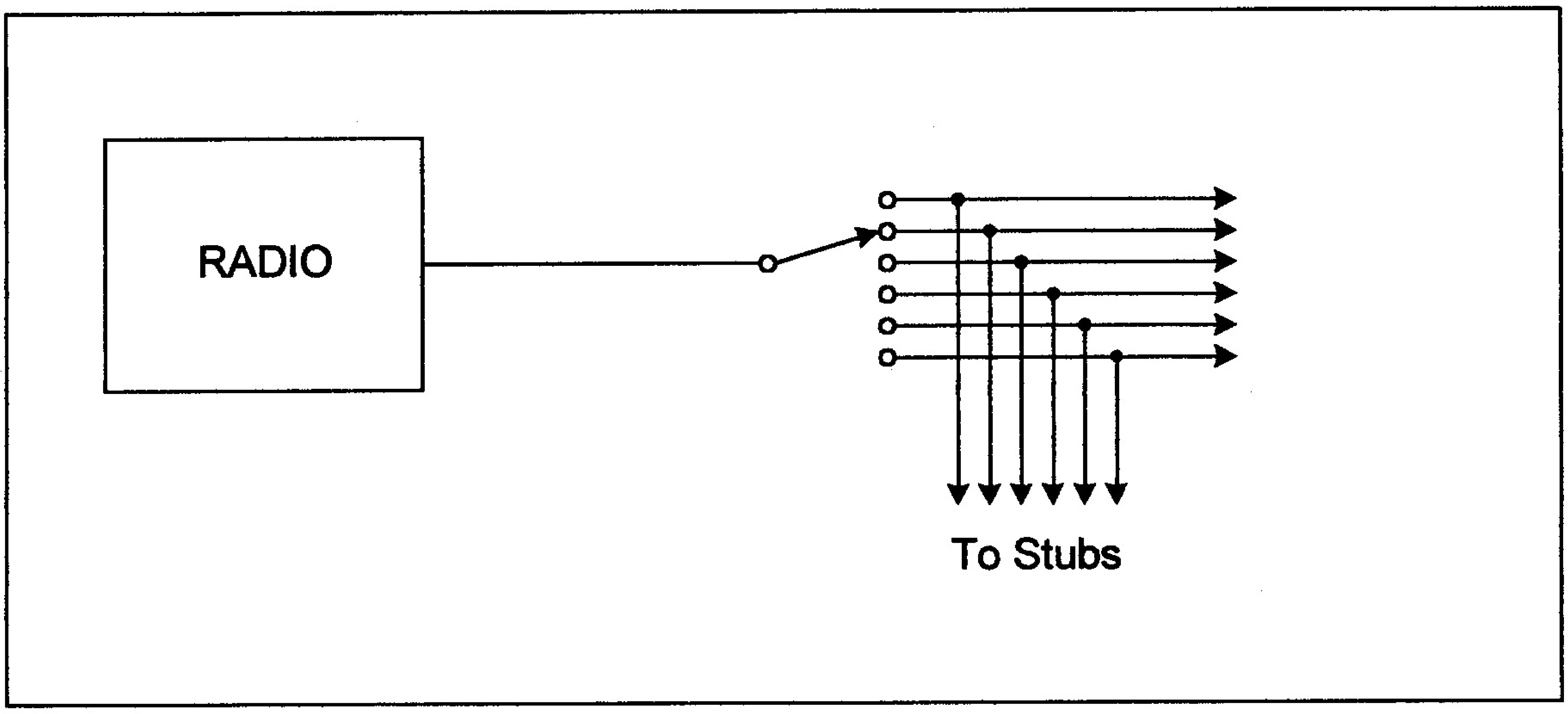


Figure 30 Common switching of stubs and antennas.

Type 8 stubs (see Table 10) can be switched with two relays to be used on four bands. See Figure 31. Relay K1 grounds one end of the stub when not energized and connects it to the output when energized. Relay K2 opens the other end of the stub when unenergized and connects it to the output when energized. When both relays are energized the stub becomes a Type 8. With only K1 energized the stub is Type 2. With only K2 energized the stub is Type 1. If a length of 46 feet 7 inches is used, the switched arrangement is useful on four bands, as shown.

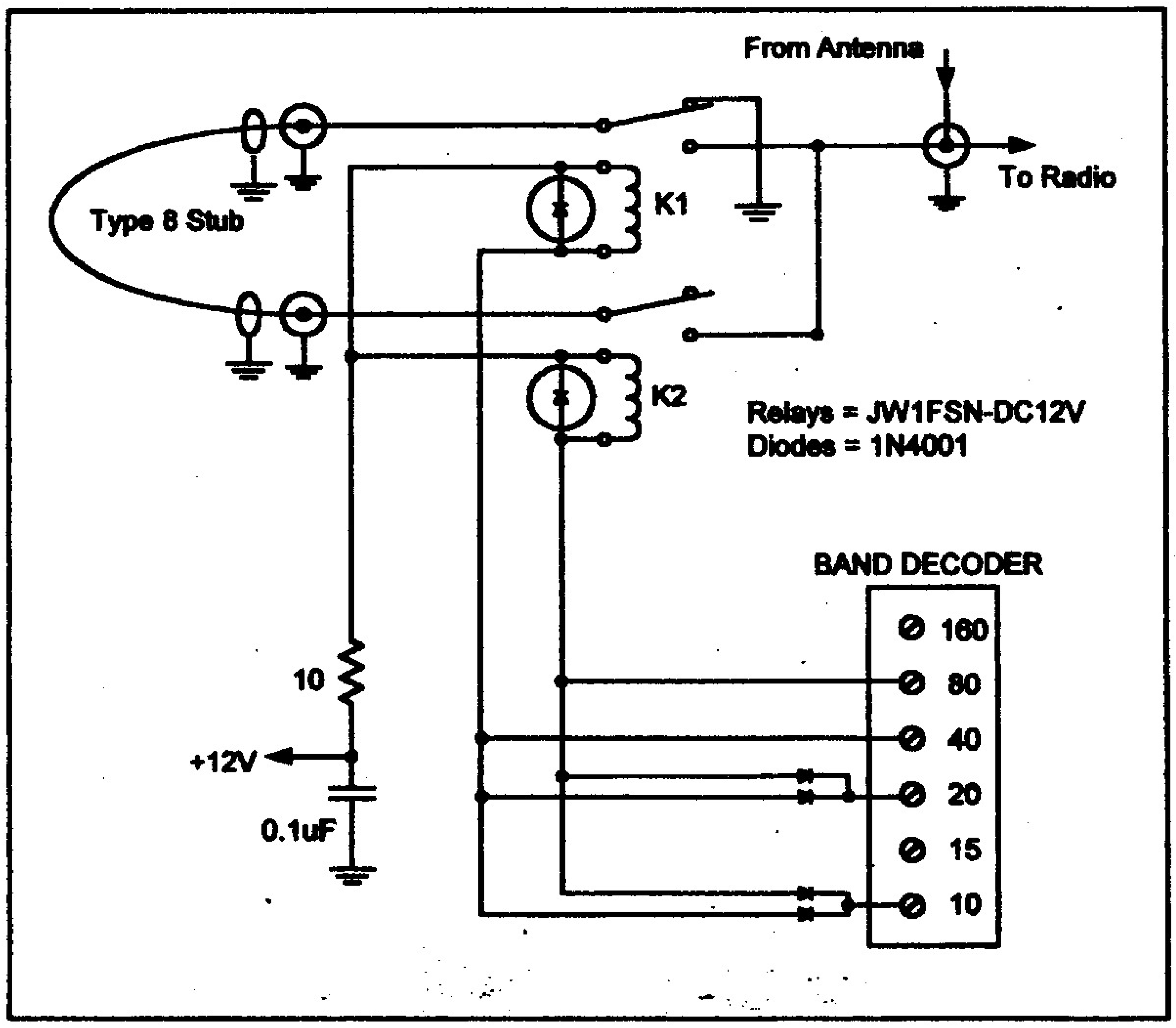


Figure 31 Bandswitching a type 8 stub for four bands.

Band switching stub assemblies can be made up in several differing combinations. One possible assembly type is shown in Table 14. It can be made with a 6 way relay switch and it provides some attenuation for all six contesting bands as shown in Table 15.

Table 14 Bandswitching method 1

Relay	160	80	40	20	15	10
1	CS1	CS1				
2	CS2		CS2	CS2		
3			CS5	CS5	CS5	
4			CS6		CS6	CS6
5				CS4		CS4
6			CS7/8			

Table 15 Bands nulled with method 1

Band passed	Bands nulled
160	80
80	40,20,15,10
40	80,20,15,10
20	80,40,15,10
15	20,10
10	40,20,15

Method 2 (Table 16) trades improved harmonic rejection on 15 meters for better rejection on 160. Other combinations can be arranged as desired. If a switch with more than six positions is used, additional stubs can be accommodated.

Table 16 Method 2.

Relay	160	80	40	20	15	10
1	CS9					
2		CS1				
3			CS3		CS3	
4				CS4		
5				CS5		CS5
6						CS6

The diode logic required to do the switching for these methods can be determined directly from the tables. Consider that a band decoder is driving the relay box and we are using method 1 bandswitching. Diodes would be connected from the band outputs to the relays as follows:

160	to 1 and 2
80	to 1
40	to 2,3,4,and 6
20	to 2,3, and 5
15	to 3 and 4
10	to 4 and 5

This is shown schematically in Figure 32. The relays ground all of the unused stubs. Diode protection is needed on each relay to keep the fly back surge from damaging the band decoder transistors. A 10 ohm resistor in the power line protects the pc traces from shorts on the power bus. A bypass capacitor keeps stray RF from getting back onto the power supply input. This schematic is for the Top Ten Devices Six Way Relay Box, but may be easily home built. The relays have 10 Ampere contacts and are very reliable. There are thousands of them in use worldwide. The band decoder requires a "sink" output for this schematic. That is, it must supply a ground to activate the desired relay. To accommodate a decoder with "source" outputs, the diodes all must be reversed and the +12V input should be grounded.

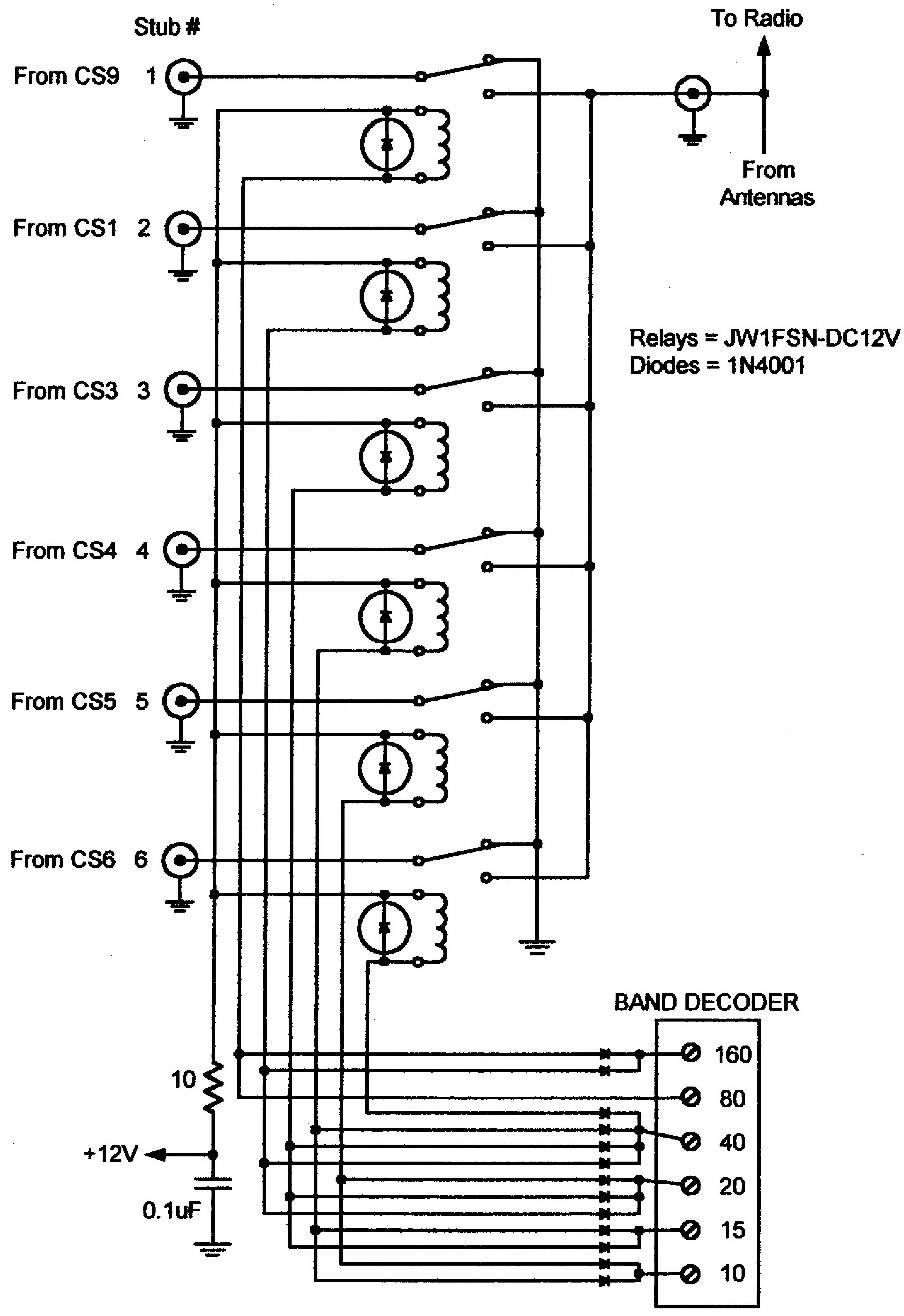


Figure 32 Bandswitching stubs by method two.

Another method using a switched Type 8 stub is shown in Table 17. All normally closed relay contacts are grounded except for relay K2, which is open circuited.

Table 17 Method 3

Relay	160	80	40	20	15	10
1	CS2S		CS2S	CS2S		CS2S
2		CS2F		CS2F		CS2F
3			CS3	CS3	CS3	
4			CS4			CS4
5					CSXX	
6	CS2	CS2				

Note. CS2S and CS2F refer to a two ended CS2 with a start and a finish (i.e. a Type 8.) CSXX refers to a Type 5 stub that has no CS number.

3.9 Tuning Stubs with Lumped Elements

Adding a capacitor or inductor to a stub in various ways will shift the stub null frequency. Reasons for doing this include the following:

1. Very small increments can be made which might be difficult to cut.
2. If a stub is inadvertently cut too short, it can be lowered to the desired frequency with a fixed inductor or capacitor.
3. Large changes in frequency can be made without changing the stub length.
4. One stub can be used on two frequencies under relay control; i.e. SSB and CW.
5. One stub can function as a shorted Type 1 or an open Type 2 and may be tuned to any frequency between the two nulls.

Several simulations were done to test the amount of variation obtainable. In all of the examples a 23' 4" stub was used. When shorted it has nulls at 14,000 and 28,000 kHz. When open it has nulls at 7,000 and 21,000 kHz. We examine the primary, or lowest, null in each case. Figures 33a and 33b show two ways to inductively load a Type 1 stub. In both cases the frequency is shifted lower. The resulting shift in frequency is identical for the two circuits shown. The inductors used are very small. An inductor as small as 0.02 uH will shift the null in this example by 155 kHz at 14 MHz. An inductance of this amount can be produced with one inch of wire.

Figure 33c shows a series capacitor used to increase the frequency of a Type 1 stub. Large values of capacitance are needed to shift the frequency in small amounts. The capacitor can be placed in series with the stub input or it can replace the short circuit on its far end as shown in 33d. The same shift occurs as capacitance is varied in either case.

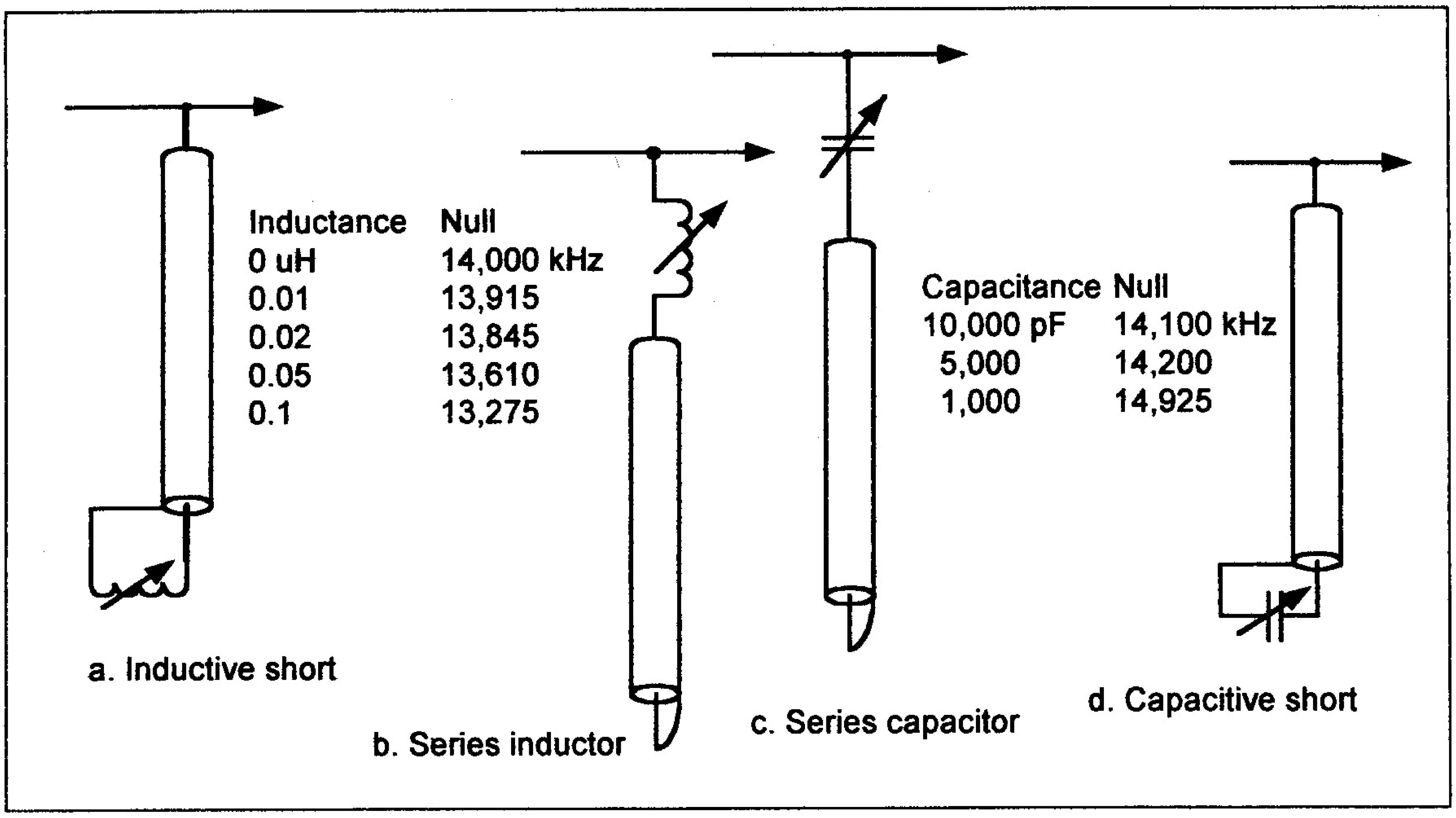
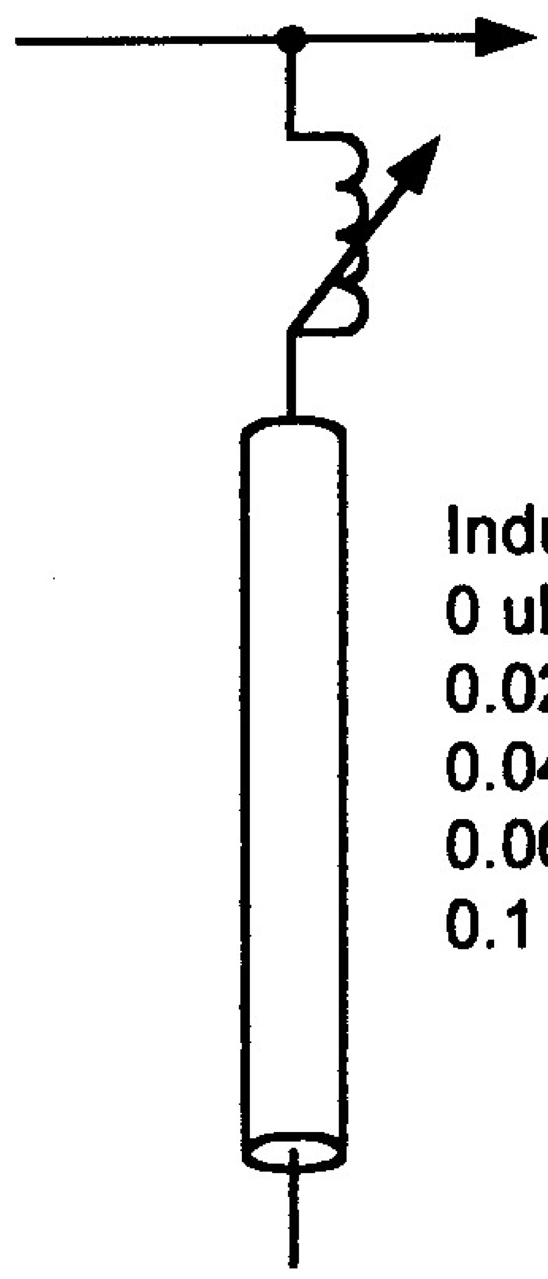


Figure 33 Tuning a shorted stub.

Figure 34 shows the tuning methods applied to a Type 2 stub. In all of the examples a 23' 4" stub was used. Again, when placed in series with the input to the stub, an inductor is used to lower the frequency and a capacitor is used to raise it. Results are shown in Fig 34 a and b.

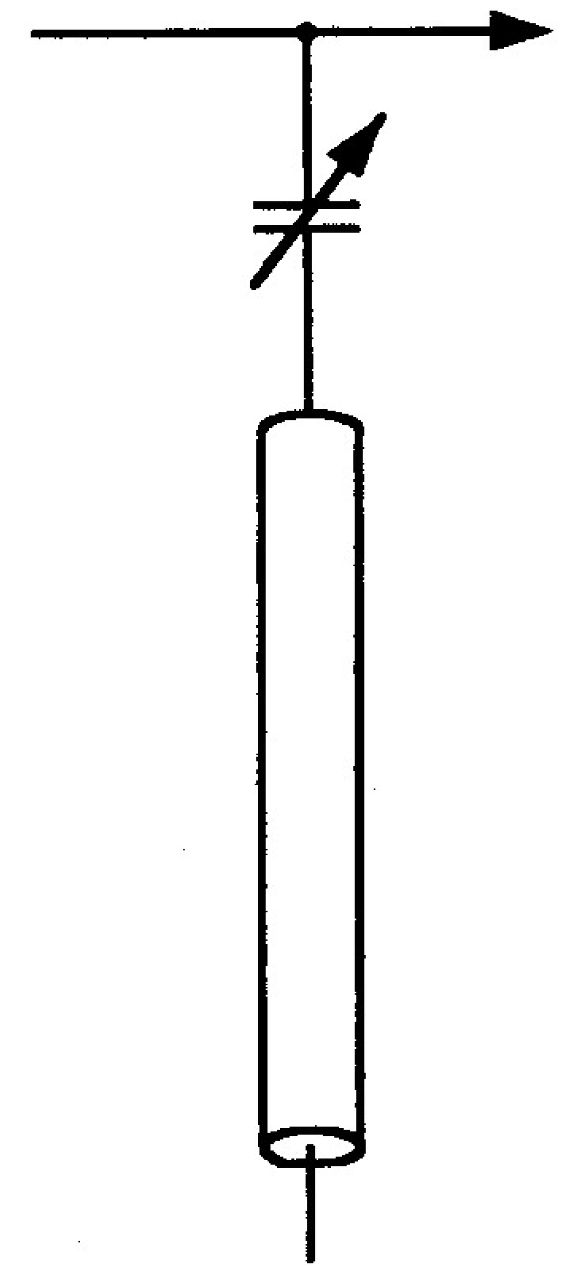
In 34c a capacitor at the far end of the stub is shown. In this case the frequency is shifted lower by some very small values of capacitance. Note that this appears to be the same schematic as Figure 33d. If we start with a shorted, or Type 1 stub and replace the short with a very large capacitor, the null at 14 MHz moves up very slightly. However, with a short there is also a null at 0 frequency (d.c.). Replacing the short with a capacitor moves this null up in frequency to some low value. As the capacitance is reduced, the nulls move up in frequency. When the capacitance is reduced to the low pF range, the nulls are as seen in Figure 33c. When the capacitance goes to zero, the stub is a Type 2.

If high quality components are used for tuning the stubs, there will be little or no reduction in the null depths obtained without the lumped elements.



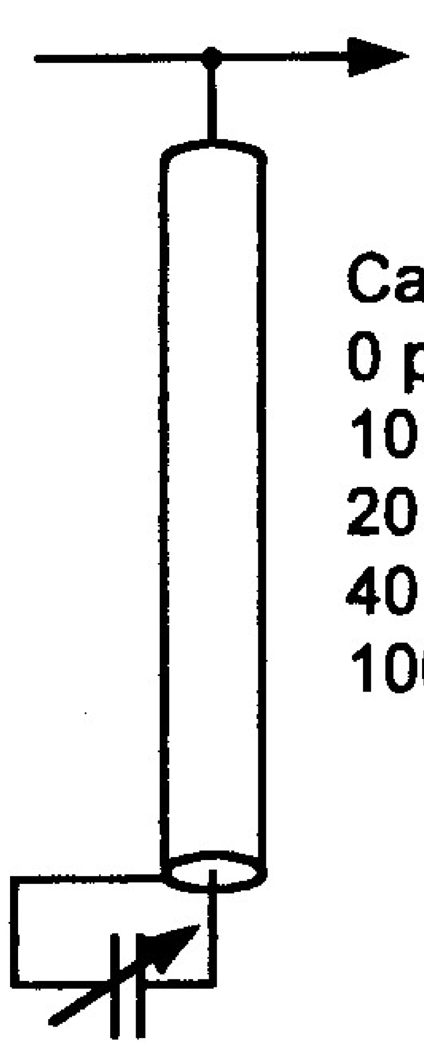
Inductance	Null
0 uH	7,000 kHz
0.02	6,915
0.04	6,845
0.06	6,775
0.1	6,630

a. Type 2 stub with series inductor



Capacitance	Null
Infinite	7,000 kHz
10,000 pF	7,200
5,000	7,400
1,000	7,890

b. Type 2 stub with series Capacitor



Capacitance	Null
0 pF	7,000 kHz
10	6,905
20	6,810
40	6,630
100	6,160

c. Type 2 stub with Capacitor loading

Figure 34 Tuning an open stub.

Figure 35 shows the response of a pair of Type 1 stubs coupled with a 1/8 wave line. If both stubs are cut for nulls at 14,050 kHz, a –61 dB null occurs. When both are cut for nulls at 14250 kHz, the null occurs in the SSB band. If one of the stubs is cut for 14,050 and the other is cut for 14,250, the broad null depth is about –55 dB. With both stubs cut to null at 14,050 kHz and one has a 5,000 pF capacitor inserted as shown in figure 34c, the double null produced is almost identical to the previous example using two different cuts. When both stubs are cut for 14,050 and modified with 5,000 pF capacitors, the SSB null created is similar to cutting them for SSB. With relay selection of a short or a 5,000 pF capacitor at each end, any of the three characteristics shown could be obtained remotely.

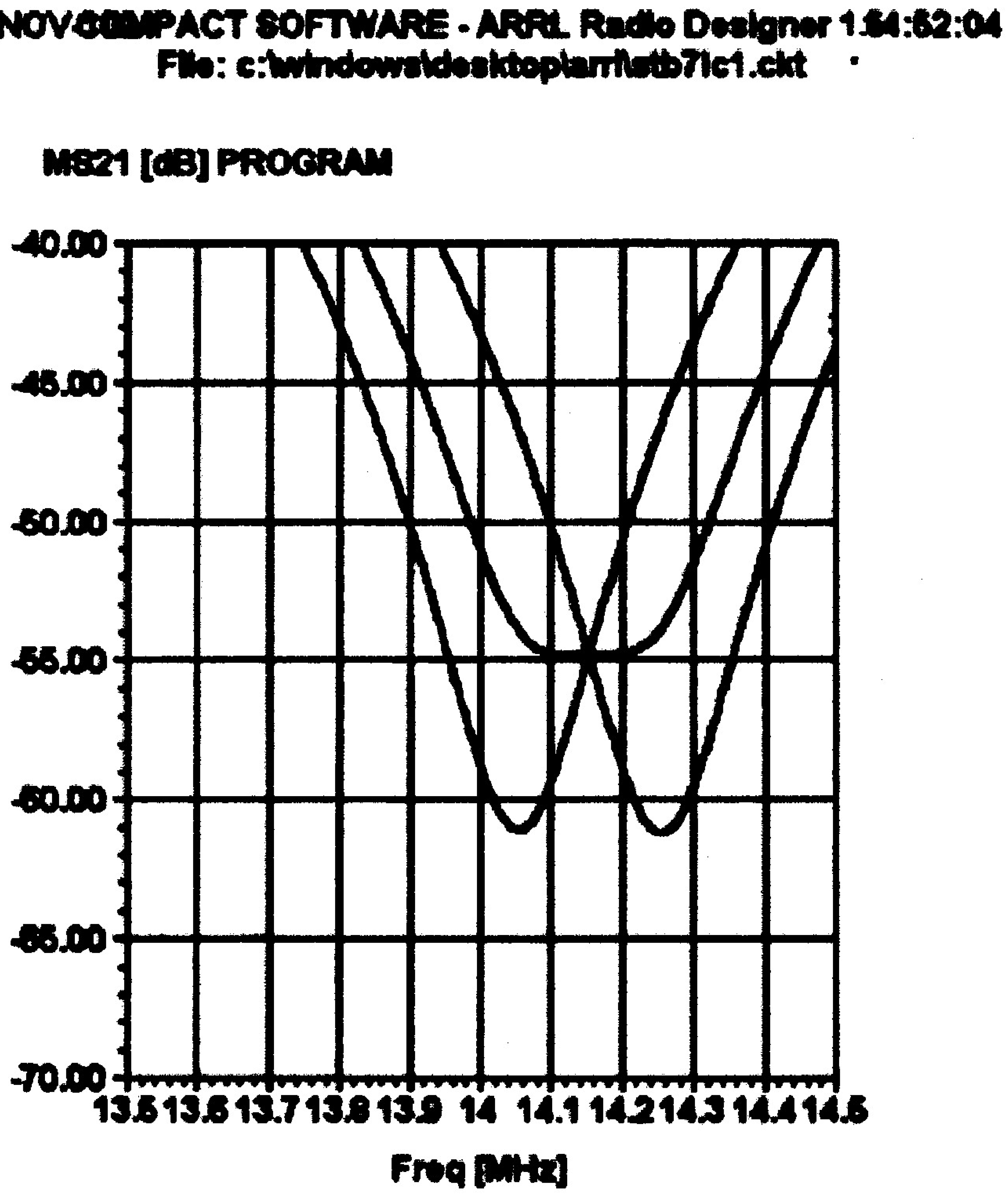


Figure 35 Tuning a pair of stubs.

<u>4.0 FILTERS</u>

4.1 Bandpass Filters

Bandpass filters would seem to be the ideal way to improve isolation in the multi transmitter environment. Radio 1 is transmitting on band 40 and radio 2 is receiving on 20. The 40 meter signal needs to be reduced at the input of radio 2. A bandpass filter on radio 2 which passes 20 and removes 40 should do the job. Radio 1 is also transmitting some harmonic energy on 20 which will interfere with radio 2, even with the bandpass filter in place. Thus a second bandpass which passes 40 and removes 20 meter energy before it is transmitted filter is needed on radio 1.

So there are two uses for bandpass filters: transmitter harmonic reduction and out of band energy reduction for receivers. Protecting the receiver from out of band energy is not a difficult task. The energy levels involved are low, usually less than 10 Watts. Filters can be designed using small, inexpensive components which will do a good job when placed in the receiver input. Transmitter harmonic reduction presents a more stringent requirement on the components needed. Most of the commercial filters available in the amateur market are designed for 100 or 200 Watts maximum. While it is not impossible to design a bandpass filter which will take 1500 Watts, the components required for such a design are quite expensive.

The simplest bandpass filter that is of any use is the two pole type. Several of the commercially available units for amateur use are two pole designs. Three pole filters provide a bit more attenuation and are not much more difficult to design and build. While there are several circuit configurations that can be used, the two resonator, top coupled arrangement is probably the most common design. It uses a minimum of parts and the component spread is not excessive.

Figure 36a shows the response of a home designed 160 meter bandpass filter. Note the excellent isolation from 15 to 20 MHz of greater than 75 dB. Beyond 30 MHz there is some "fly back" which increases as the frequency goes higher. This type of response is typical of filters built with leaded components. The parasitic inductance associated with the capacitors causes the attenuation to degrade as the frequency gets higher. Since the fly back is outside the frequency range of interest, it is of little concern in this case. Leadless components will have much less of this type degradation.

Figure 36b shows the response of a commercial single band 20 meter bandpass filter. The stop band rejection is quite good.

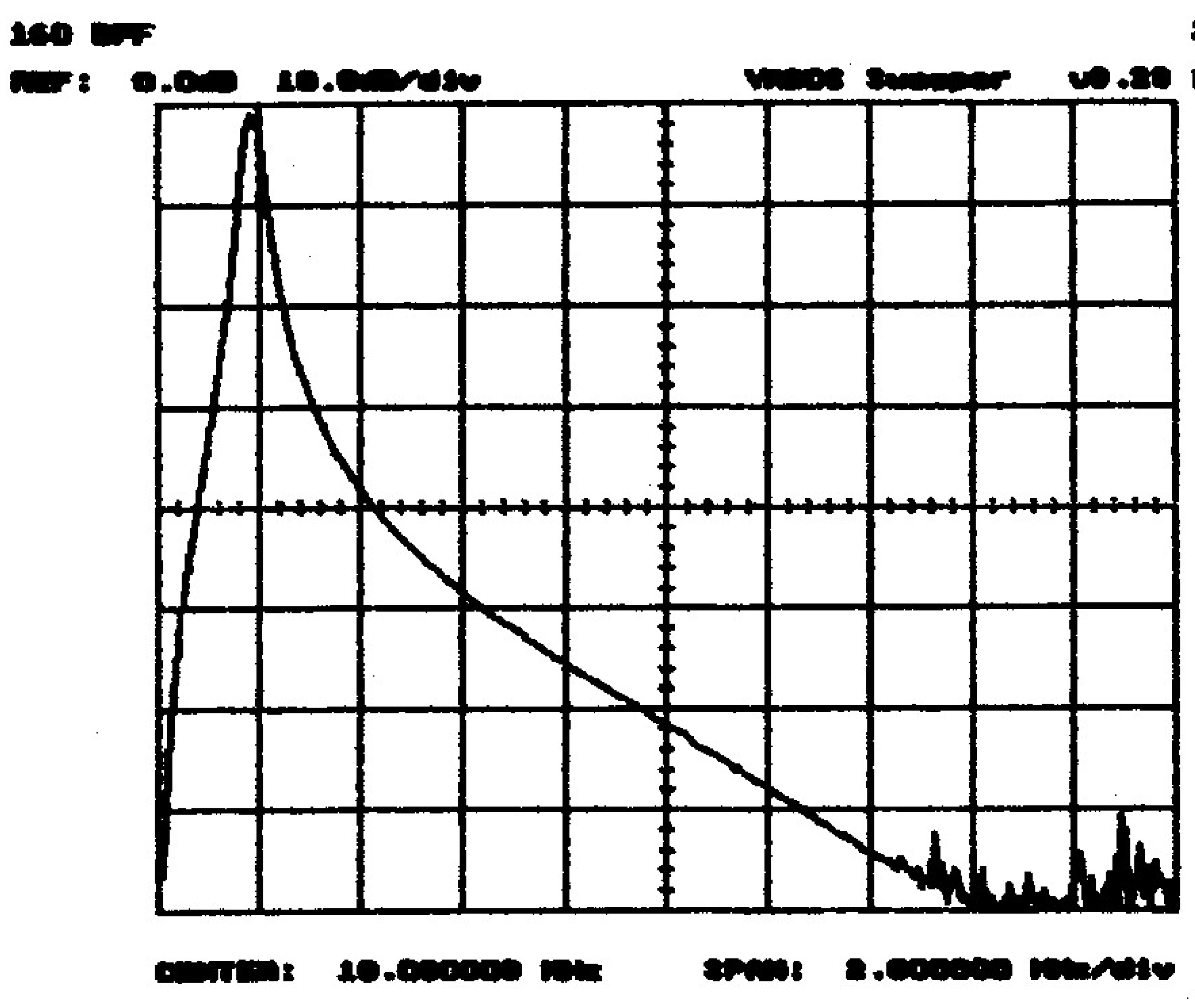


Figure 36a. The 160 meter filter.

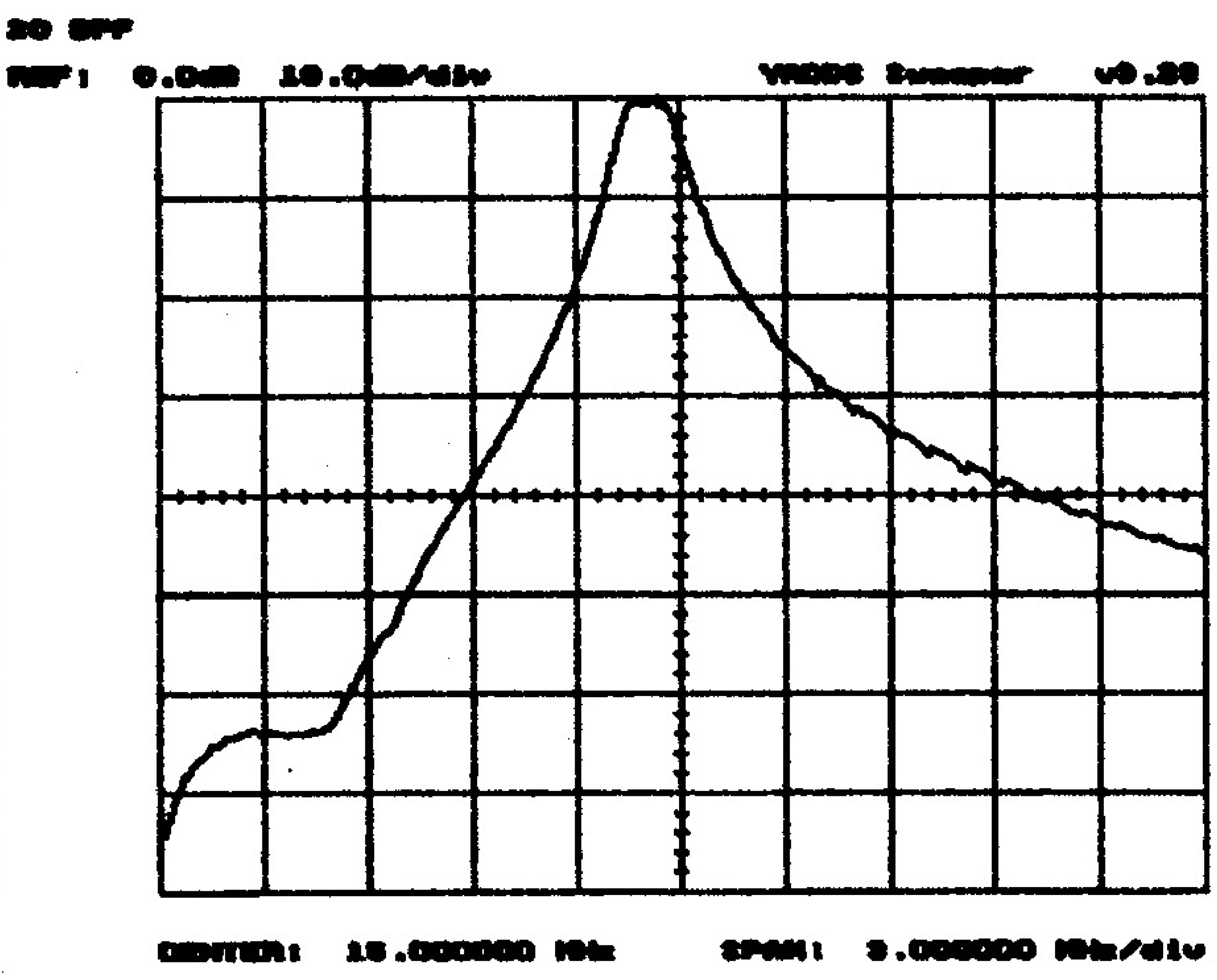


Figure 36b. A commercial 20 Meter filter.

Figures 37a through 37d show the response of a commercially made band switching filter. Figure 37a shows the responses for 160, 80 and 40 meters with overlapping plots. The responses of these three filters continue into figure 37b, which shows the 10 to 30 MHz range. Figure 37d shows the responses for 20, 15 and 10 meters. The response for these three filters in the 0 to 10 MHz range is shown in figure 37c. The effects of the additional wiring and relays on the fly back in the stop band are clear. The ultimate rejection on this filter is much inferior to single band units.

Table 18 shows the band to band attenuation. The top line is the transmitting band and the left column is the receiving band. For example: The transmitting band is 40 meters, so the filter in use is 40. When receiving through the 40 meter filter, 80 meter energy is attenuated by 18 dB, etc. To meet our "no damage" goal of –45 dB, an additional 27 dB of isolation is required. Hopefully, the antenna to antenna isolation will exceed that.

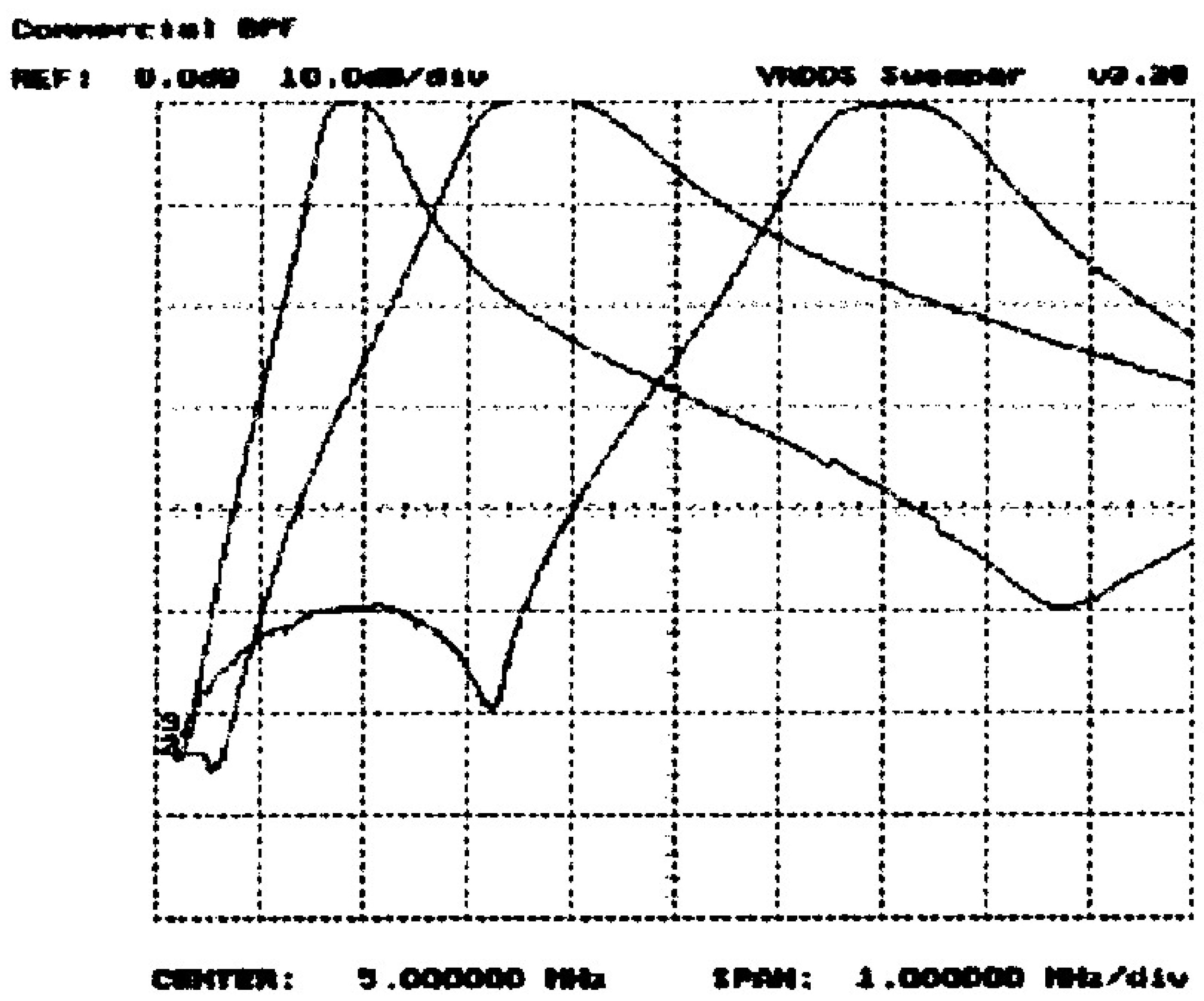


Figure 37a 160-40 passband

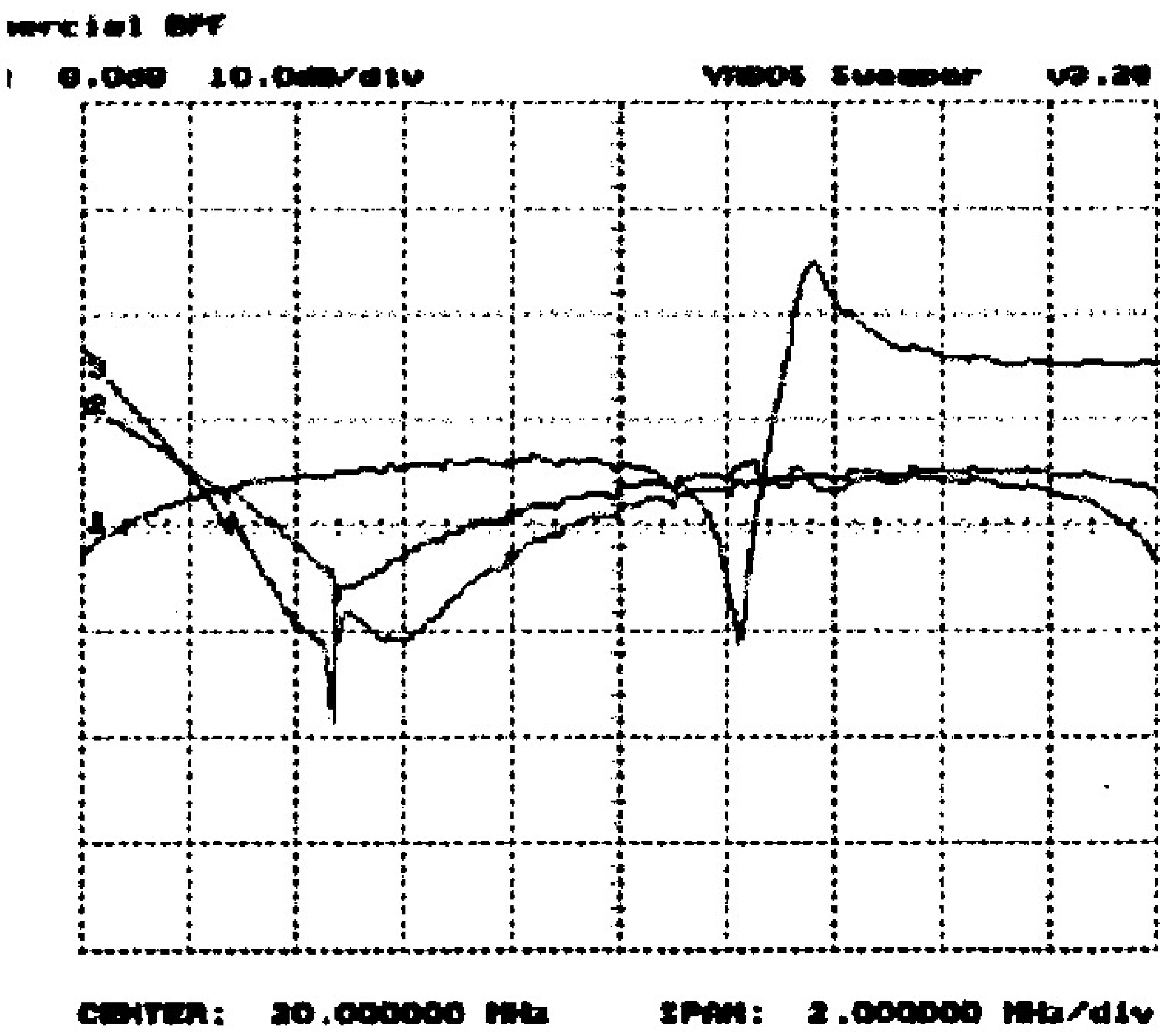


Figure 37b 160-40 stopband

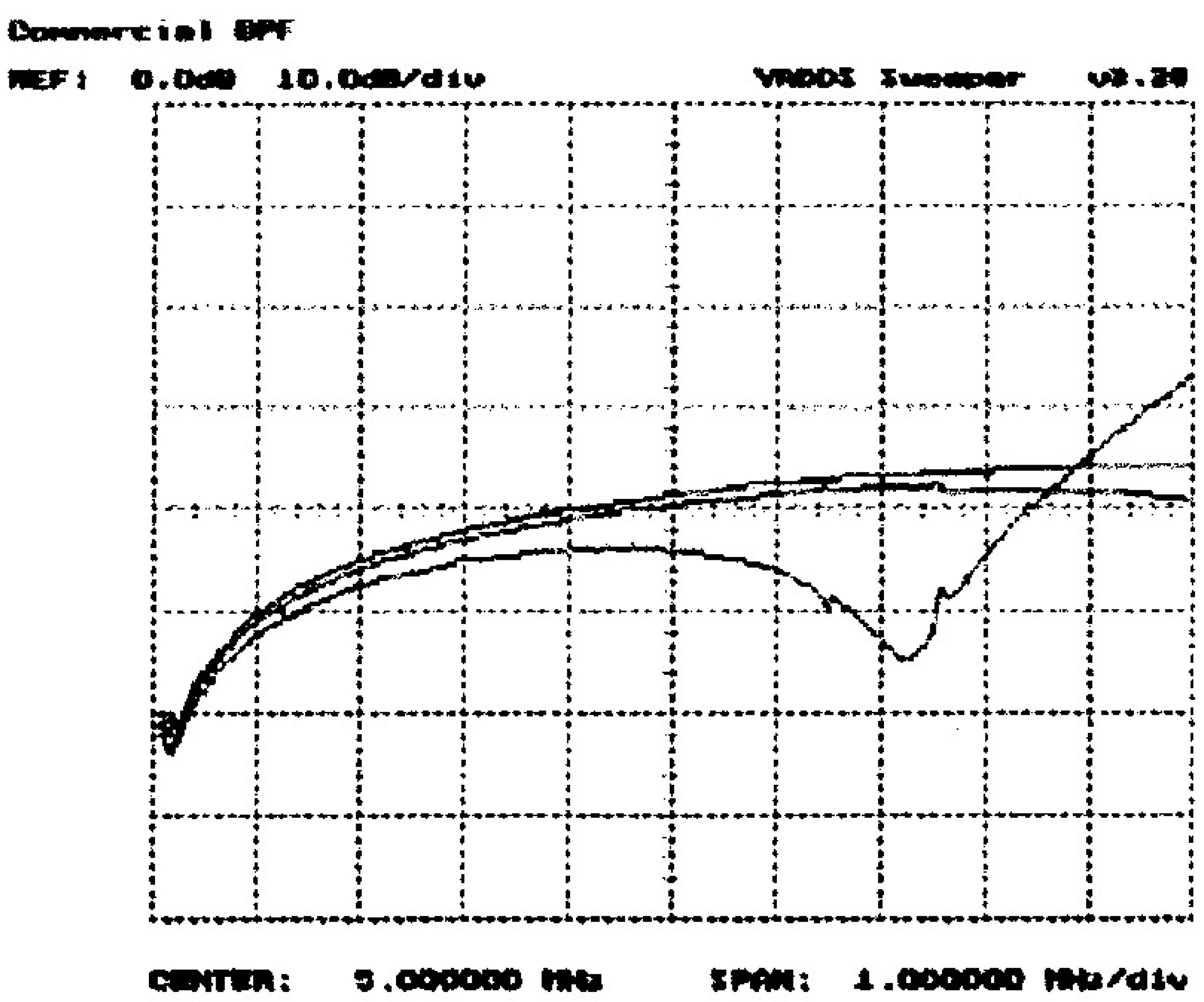


Figure 37c 20-10 stopband

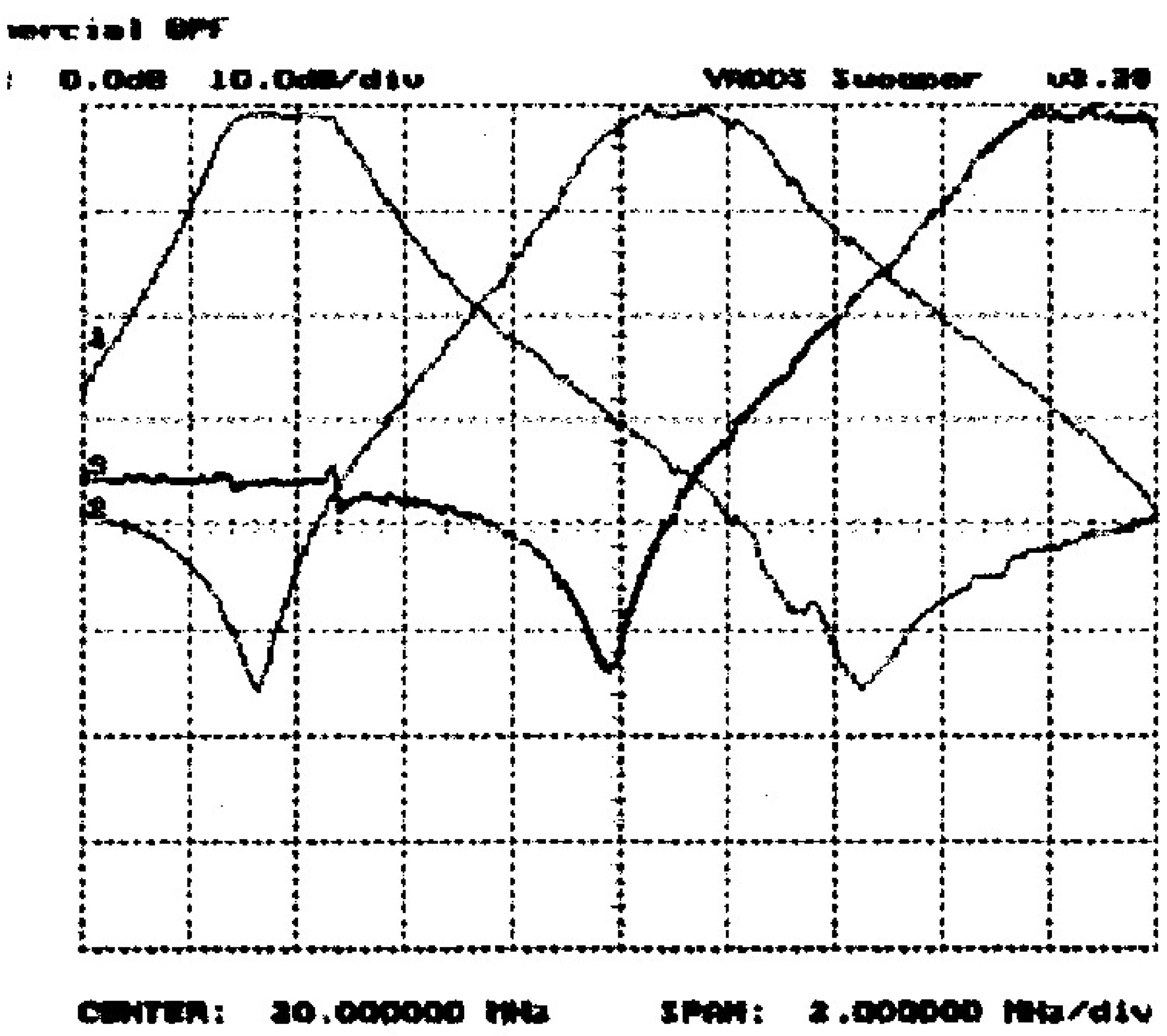


Figure 37d 20-10 passband

Figure 37 A commercial bandswitching filter.

Table 18 Commercial band switching filter response

Tx	160	80	40	20	15	10
Rx						
160	_	-20	-38	-36	-35	-23
80	-27	_	-18	-42	-36	-35
40	-50	-50	_	-50	-36	-35
20	-48	-44	-52	_	-34	-41
15	-47	-41	-37	-43	_	-29
10	-46	-40	-37	-36	-36	_

4.2 Hybrid Low Pass Filters

Low pass filters using standard inductors and capacitors typically have a rather slow roll off above the cutoff frequency unless they are constructed with a lot of components. Since we are interested in harmonic reduction from our transmitters and not concerned with frequencies in between harmonics, stubs usually give better performance. It is possible to combine the standard low pass filter using lumped components with stubs to improve the performance at the harmonics. Low pass filters are composed of series inductors and shunt capacitors. Open circuited transmission lines having an equivalent capacitance can replace the capacitors. This technique is easily understood by using an example. Figure 38 shows a 5 element Butterworth low pass filter in normalized form; i.e. the cut off frequency is 1 radian/second and the impedance is 1 ohm.

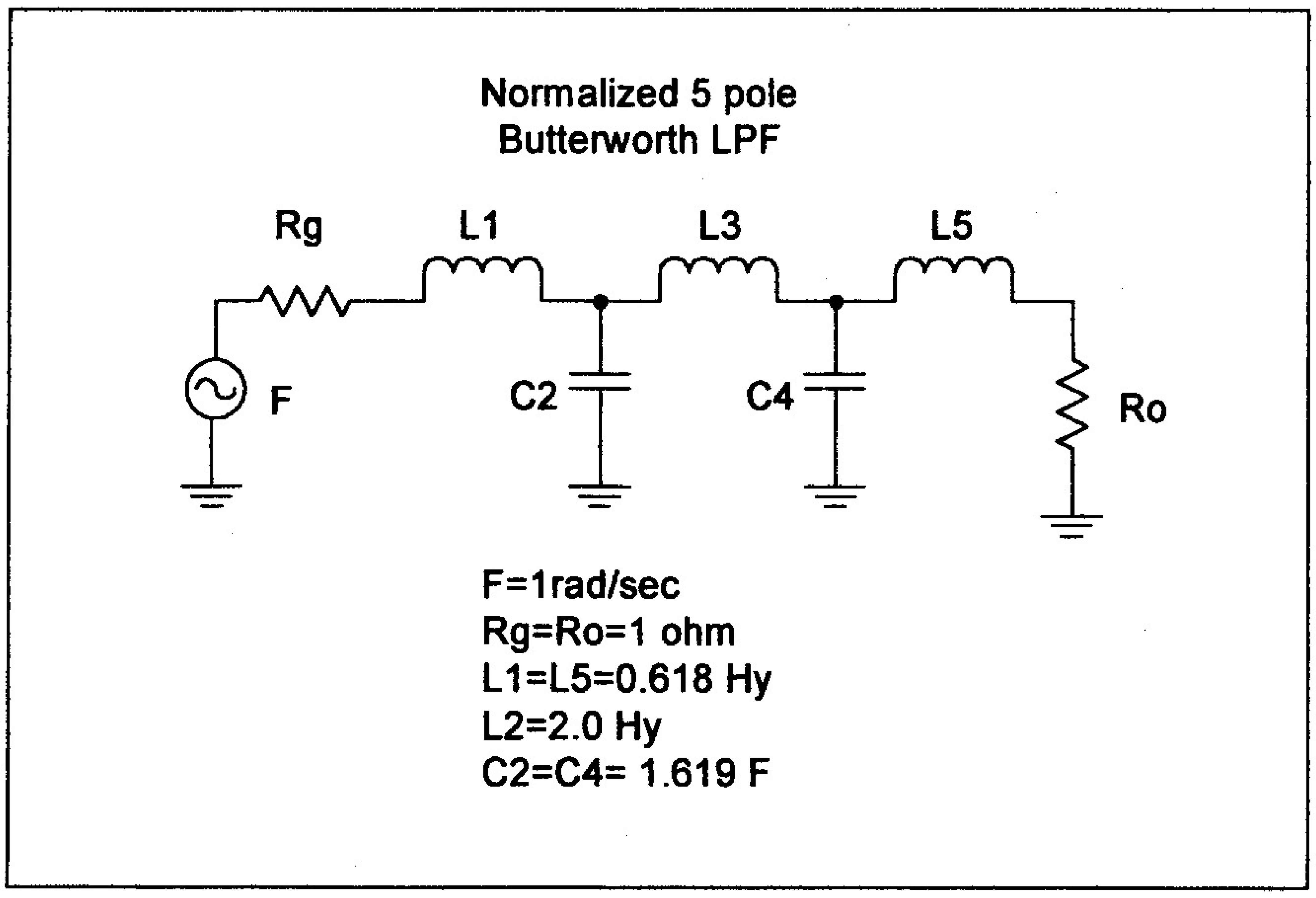


Figure 38 The normalized low pass filter.

Let's say we want to pass 7 MHz and null the second, third and forth harmonics. C2 will be replaced by an open circuit stub, which is ¼ wave long at 14 MHz. C4 will be made up of two open circuit stubs in parallel where one is ¼ wavelength at 21 MHz and the other is ¼ wavelength at 28 MHz. We can calculate the capacitance of these stubs by considering their length and the capacitance per foot of the coax in use. Figure 39 shows the schematic of the completed filter with the stubs in place. S1 will be cut to null 14 MHz. Its length is calculated as shown below.

S1 = ¼(983.6/14 x 0.785) = 13.79 feet

Where 0.785 = the Vp for RG8X

An open circuit line of that length will have a capacitance of 29.5pF/ft x 13.79 ft = 406.75 pF. Likewise, S2 and S3 may be calculated as follows:

S2 = ¼(983.6/21 x 0.785) = 9.19 ft

And the capacitance is:

C(S2) = 9.19 x 29.5 = 271.2pF

S3 = ¼(983.6/28 x 0.785) = 6.89 ft

And:

C(S3) = 6.89 x 29.5 = 203.37pF

Adding C(S2) and C(S3) we get 474.53pF.

In the normalized circuit we can see that the two capacitors are of the same value. So we will use 474.53pF as the un-normalized, or final, value. This is where we work backwards to find what cutoff frequency is required to use this capacitance. To un-normalize the value of C4 we would use the following relationship. .

C4' = 1/ (C4 x 2 x pi x Fc x Z)

Where C4' is un-normalized and C4 is normalized

And Fc is the cutoff frequency

And Z = desired impedance = 50 ohms

Rearranging we can solve for Fc.

Fc =C4' / (C4 x 2 x pi x Z)

Substituting our values gives:

Fc = 10.853 MHz.

At this point, if the Fc determined is about 1.4 or more times the desired operating frequency, the design will work well. If not, the attenuation at the operating frequency can be excessive. The types and numbers of open circuit stubs can usually be adjusted to make this happen. Sometimes Tchebyshev filter element values will provide a better fit for the stubs needed for a particular finished product. The normalized values for various filter characteristics are shown in many books, some of which are listed in the references.

The inductor values can be calculated once the Fc is determined. The following formula is used to un-normalize the inductors:

L' = (L x Z)/(2 x pi x Fc)

So, *L1'* = L5' = *(0.618 x 50)/(2 x pi x 10.853 x 10^6)*

And *L1' = 0.453 uH = L5'*

And *L3' = 1.466 uH*

Since S1 and S2 + S3 are not equal in capacitance, a compensating capacitor must be added. This would be:

Cc = S2 + S3 – S1

And *Cc = 474.53 – 406.75 = 67.78 pF = 2.3' of RG 8x*

This can be a lumped capacitor or another length of open circuit coax placed in parallel with S1.

The stubs in this filter are not resonant at the operating frequency. Rather, they are used as capacitors and considerable RF current will flow through them. When these filters are used at high power there may be some heating. If this occurs, a larger coax may be used. In the case of this 7 MHz filter, S1 was running warm under power and was replaced with RG-213. Since the Vp is different, the length is also different and this results in a different capacitance. It also requires a change in the value of Cc.

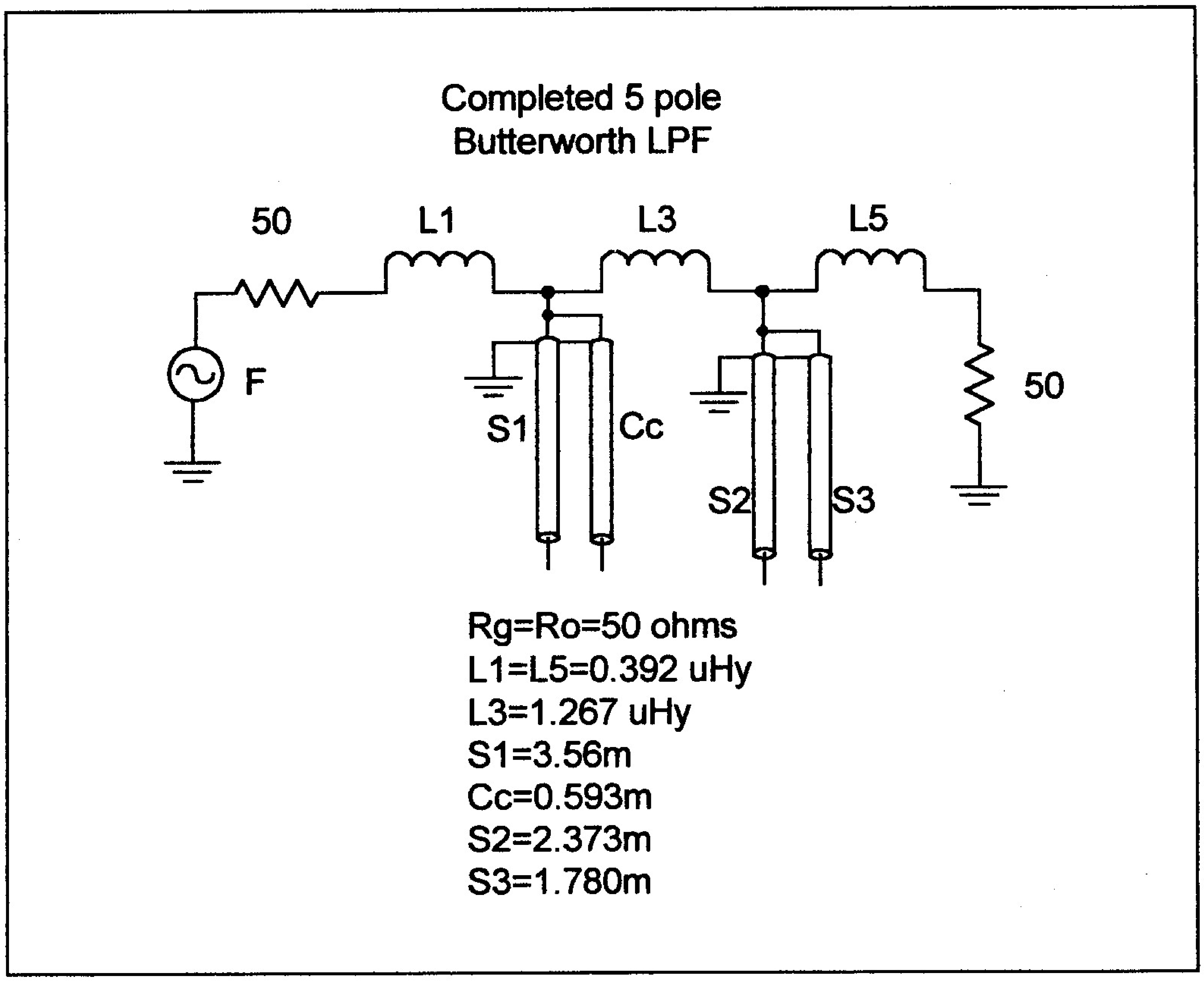


Figure 39 Hybrid version of the low pass filter.

An ARD simulation of the completed filter is shown in Figure 40. Also shown is the plot of the original LC only filter, without the stubs. The improved attenuation at the harmonics is quite impressive.

Additional rejection can be obtained by adding resonant stubs to the filter. Type 1, shorted quarter wave stubs could be put on the input and output to increase the rejection at 2F and 4F. Type 2, open circuit half wave stubs could also be put at the filter input and output to create a null at F/2 without changing the original characteristic.

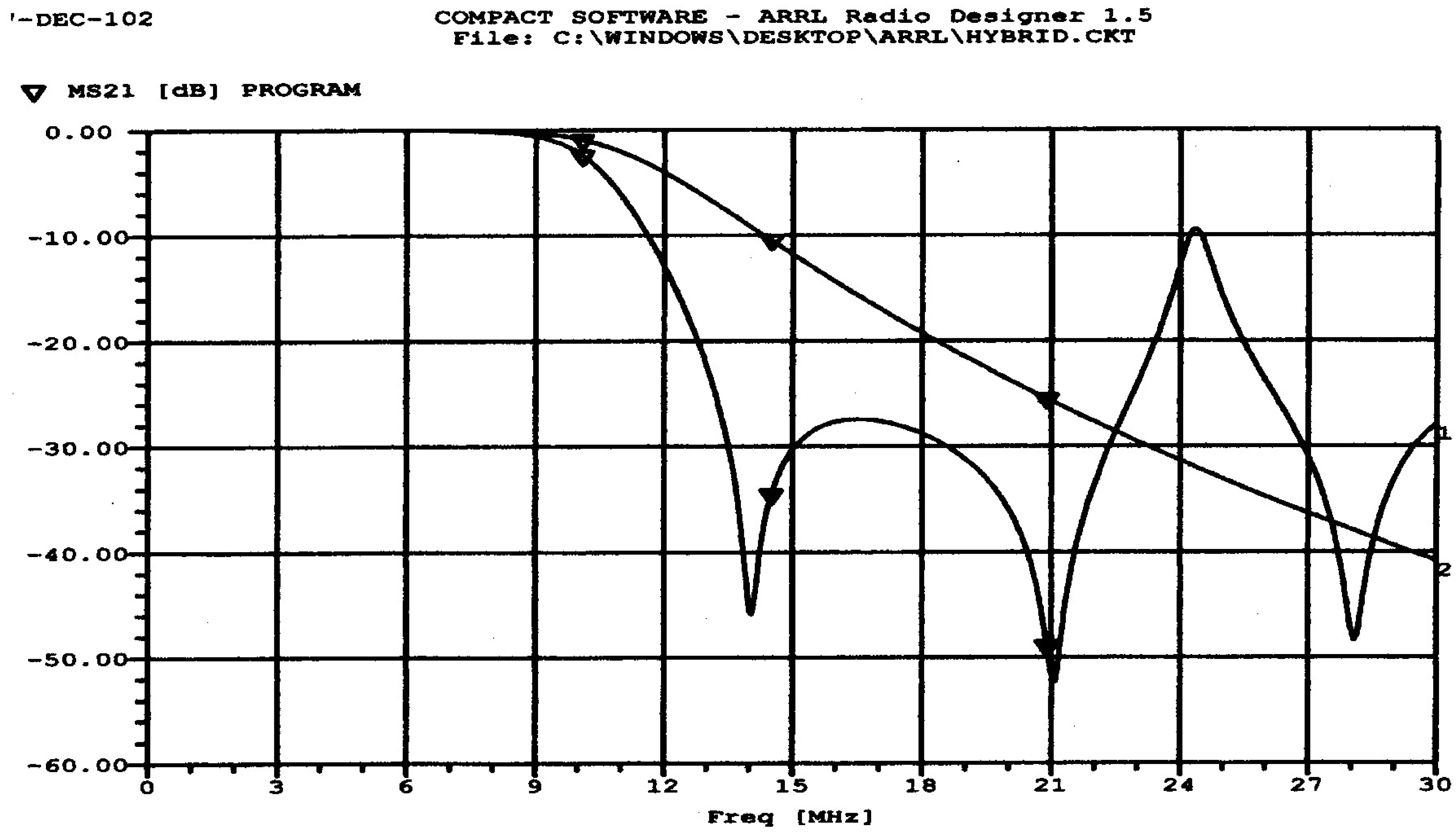


Figure 40 Response of the hybrid filter.

5.0 THE TWO RADIO, ALL BAND STATION

Many operators choose to use two radios while operating all band contests, the only restriction being that just one can transmit at a time. Usually, one radio is used for running stations while the second is used for finding multipliers or other stations that have not been previously worked. Figure 41 shows a typical block diagram for such a station.

Each chain consists of a radio, a band pass filter, an amplifier and a 6 way antenna selector switch. The outputs of each 6 way switch are joined in a set of six A/B, or two-way switches. Following each A/B is a set of stubs for the particular band involved. The antenna for each band then is connected via transmission line to the stub set. Usually an automatic band decoder is used to select the bands in use by the BPF and the switches.

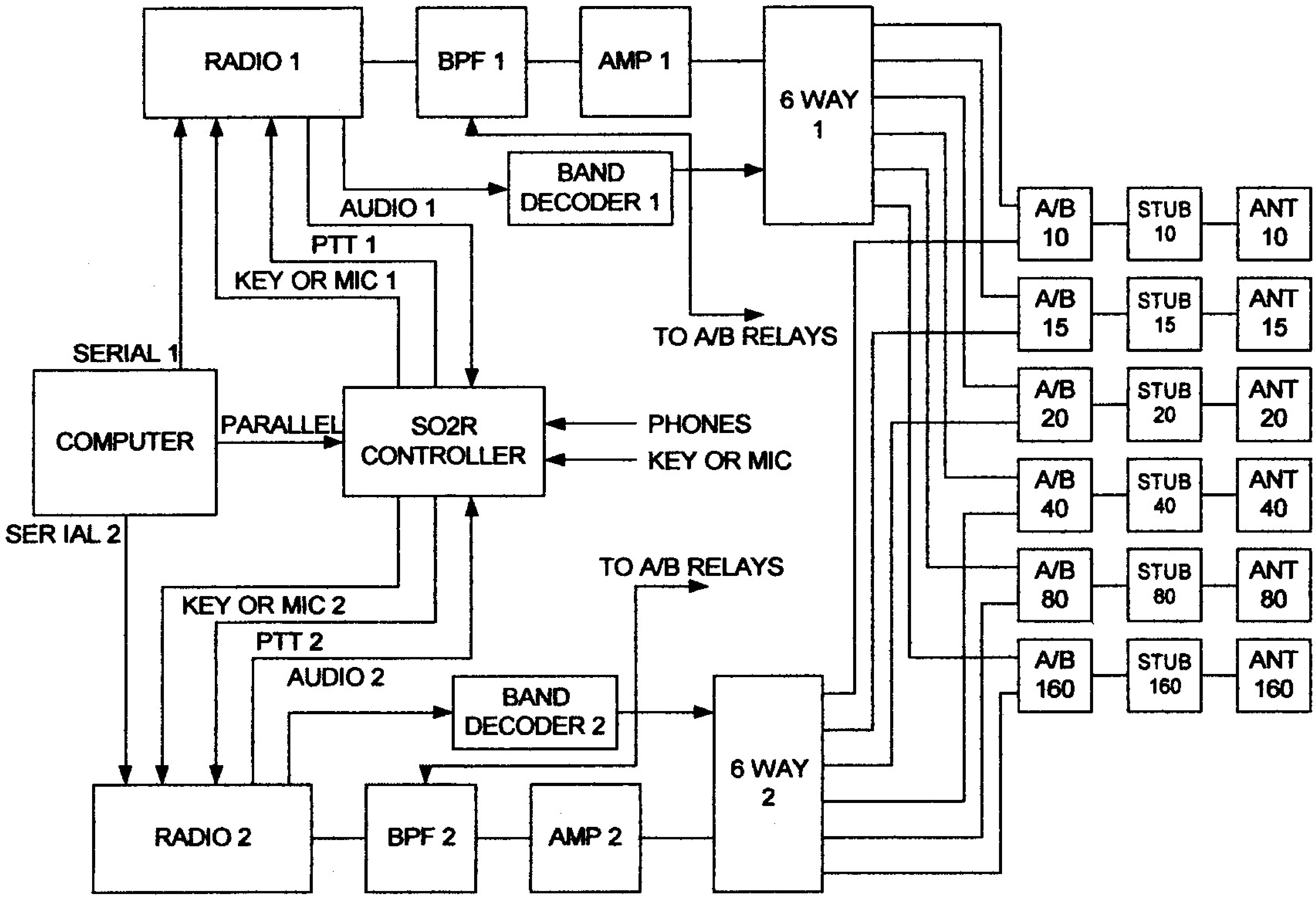


Figure 41 An SO2R equipment setup.

The characteristics of the radio, BPF, stubs and amplifier have been covered in previous sections. The 6 way and A/B switches used in this example are those manufactured by Top Ten Devices, Inc. Typical isolation between ports on the 6 way switches is 40 dB. The isolation of the A/B switches is 85 dB on 10 meters, 95 dB on 20 meters, and even greater on the lower bands.

Note that there are two paths which energy may take to get from one radio to the other. The obvious path is through the 6 way, through the A/B, through the stub assembly, out the antenna then back into the second antenna, etc.

From Figure 1, the dBm ladder, we have learned that we need about 147 dB or more isolation to run a second radio with little interference. Let's see what a typical set up like our SO2R station would look like.

Lets assume that Radio 2 is transmitting on 20 meters and Radio 1 is receiving on 10. Table 19 lists the attenuations for the fundamental and harmonic components being transmitted.

The 20 meter radio 2 transmitting energy is 140 dB down and so is the 10 meter second harmonic at the radio 1 receiver.

TABLE 19 Radio 1 isolation from radio 2 through antenna coupling.

	20 meter fundamental	10 meter 2nd harmonic
Power out reference	0 dB	-40 dB
Antenna isolation	-35 dB	-35 dB
BPF	-40 dB	0 dB
Single stub	-30 dB	-30 dB
Double stub	-65 dB	-65 dB
Isolation (1 stub)	-105 dB	-105 dB
Isolation (2 stubs)	-140 dB	-140 dB

The not so obvious path is from the 6 way port which is transmitting to the port which is in use by the second radio's A/B switch and then through the A/B switch isolation. For example: Radio 2 is transmitting on 20 meters and Radio 1 is receiving on 10. Some fundamental and 2nd harmonic energy pass from the 6 way 20 meter port to its 10 meter port. From there it goes to the 10 meter A/B and passes through to the 10 meter receiver of Radio 1. Table 20 lists the attenuations obtained through the switch leakage paths.

TABLE 20 Radio 1 isolation from radio 2 through switch leakage.

	20 meter fundamental	10 meter 2nd harmonic
Power out reference	0 dB	-40 dB
6 way isolation	-45 dB	-40 dB
A/B isolation	-95 dB	-85 dB
BPF	-40 dB	0 dB
Isolation	-180 dB	-165 dB

Since the antenna-to-antenna path has less isolation, it will be the controlling amount. However, if other types of switches are used which have less isolation this may not be true. If the switches have less isolation some of the benefit of the stub assemblies will be nullified. Note that the combined isolation of the 6 way and A/B switch is a minimum of 125 dB on 10 meters, which far exceeds any other switches useful for SO2R that are available for amateur use.

In order to enjoy the kind of isolation that is possible with these switches, great care must be taken in the station grounding and cabling. An easy performance test is to use shielded dummy loads in place of the antennas and measure the amount of isolation by listening on the non-transmitting radio. The interference level should be lower than when the antennas are in place. It's best to do this with only two bands at a time to eliminate sneak paths through unused antennas.

5.1 Using the Station Radios to Measure Isolation

It isn't necessary to have a lot of expensive lab test equipment to make some of these isolation measurements. In a multi-transmitter station the required equipment is already there. Before testing with the antennas, it's a good idea to do a test with dummy loads to verify that most of the energy transmitted is staying inside the coax and radio cabinets. Put a 100 Watt dummy load on radio 1 antenna connection, and it will act as the transmitter. A second dummy load goes to radio 2 antenna connection, and it can be a low power unit. Radio 2 will be the receiver. If there are filters, stubs or switch boxes in line, they should be included in the test. If any coax is not properly connected or if there is poor shielding on some piece of gear, it will show up in this test.

Before we can work on the isolation problem with actual antennas connected, we must reduce the coupling without the antennas. It's best to test all combinations of bands and make up a table like Table 21.

Table 21 Station to station isolation.

	Rx	160	80	40	20	15	10
Tx							
160		Nil	Nil	Nil	Nil	Nil	Nil
80		-	Nil	Nil	Nil	Trace	Nil
40		-	-	Trace	Nil	S1	Trace
20		-	-	-	Weak	-	Trace
15		-	-	-	-	S2	-
10		-	-	-	-	-	S1

The transmitting band is in column 1 and the receiver frequency is listed across the top row. This test included a pair of FT-1000MPs with 3-foot coax cables to dummy loads. The transmitting radio was set to 100 Watts. This table will be the benchmark as other components and antennas are added to the stations.

Two types of important measurements can be made with just a transmitter and a receiver. Let's say that the isolation between the 14 MHz and the 28 MHz station antennas is of interest for SO2R:

> Set up the 20 meter radio as the transmitting station and the 10 meter radio as the receiver.

Put the corresponding antennas on these radios.

Reduce the power of the 20 meter station to 1 Watt. This should be measured on a Wattmeter for most accurate results.

Set the 10 meter radio to the second harmonic of the 20 meter radio.

Press the key on the 20 meter radio and observe the S meter on the 10 meter receiver. Rotate both antennas so they are facing each other and the S meter is reading the peak value. This is the worst case direction. If the S meter is reading more than S9, insert some attenuation to reduce the reading to S9 or slightly above.

Now we are going to assume that the S meter reads S9 when the signal level is about 50 uV, or –73 dBm. We can calculate the isolation between the 20 meter station and its second harmonic on 10 meters.

Harmonic isolation = Ptx - attn –(-73 dBm) – db above S9

Where Ptx = transmitter power in dBm. (1 Watt = +30)
Attn = attenuator setting in dB

Thus, with 1 Watt, the Ptx is +30 dBm. I made this measurement with a pair of FT-1000MPs. The S meter read S9 with 18 dB of attenuation in line. Using the above equation:

Isolation = +30 - 18 + 73 -0 = 85 dB

With this much isolation it is safe to raise the transmitter power and repeat the measurement. Transmitter harmonics will be increased as power is increased, so a very low power measure will produce an overly safe isolation measure. The idea here is to find out if the harmonic will have a significantly detrimental effect.

It is also possible to determine if the fundamental power to be received on the transmitting frequency will cause damage. To do this, the setup is the same; however, radio 2 is set to the transmitter frequency while leaving the original antenna switched on it. Again set the radio 1 to 1 Watt output. Tune it in on the radio 2 and add attenuation to get the S meter off the pin. As an example, the measurement made here was S9 + 55 dB with 18 dB attenuation in line. Using the above equation, the isolation becomes:

Isolation = +30 –18 +73 –55 = 30 dB

This tells us that the 10 meter station will be receiving 20 meter energy which is only 30 dB down. If the 20 meter station is running 1500 Watts, the 10 meter receiver will absorb +62 – 30 = 32 dBm or 1.58 Watts. Clearly, this would fry some of the receiver's input components. The two antennas in use for this test are tribanders, spaced 350 feet. Tribanders represent the worst case. If monobanders were in use, the 10 meter antenna on radio 2 would not pick up as much energy when set to 20 meters.

Several measurements were made in this manner. Some of the measurements were repeated using lab equipment to see if there was correlation, and the results are shown in Table 22.

Table 22 Testing isolation with the radios

Tx Band	Rx Band	Rx Ant	S Mtr	Attenuator	Isolation	Measured
80, 1W	80	80	S9+25	18	60dB	
80, 100W	40	40	S9	0	123dB	
80, 1W	80	Tribander	S9	18	85dB	
40, 1W	40	Tribander	S9+10	18	75dB	
40, 100W	15	Tribander	S9	6	117dB	
20, 1W	20	Tribander	S9+55	18	30dB	25 dB
20, 1W	20	40	S9+40	18	45dB	46dB
20, 1W	10	Tribander	S9	18	85dB	
15, 1W	15	Tribander	S9+50	18	35dB	29dB
15, 1W	15	40	S9+35	18	50dB	44dB
10, 1W	10	Tribander	S9+60	18	25dB	30dB

Some of the combinations shown will definitely be safe with no additional isolation above the antenna separation. Eighty and 40 meters can transmit full power while the second station is using the tribander. When the transmitting station is on 20 and the receiving station is on 10 there will be 85 dB isolation for the second harmonic, but only 25 dB for the fundamental. This would not be safe. A bandpass filter or stub that adds something over 25 dB of 20 meter rejection is required to prevent damage.

The lab equipment measurements show that there is an error of +6 to –5dB in the readings obtained with the radios. We learned earlier that isolation of 47 dB is needed to prevent receiver damage when 1500 Watts is being used. Since this is a critical value, we will want to increase it to about 57 dB when measuring with radios (and not lab equipment). Thus, the table tells us that some of the combinations shown are capable of creating damage.

6.0 REFERENCES

1. *Multi-Transmitter Filters*, Fred Mass, K2TR
   NCJ, May-June 1984
   Vol. 12, Number 3.

2. *Radio Proximity Effects*, W2VJN
   NCJ, Nov.-Dec. 1996
   Volume 24, Number 5.

3. *High Power Harmonic Filters*, W2VJN
   NCJ, Nov.-Dec. 1998
   Volume 26, Number 6.

4. *Band Switching Stubs for the Single Op Two Radio Station*, W2VJN
   NCJ, Sept.-Oct. 1996
   Volume 24, Number 5.

5. *Using Double 1/8 Wave Stubs*, W2VJN
   NCJ, Jan.-Feb. 1998
   Volume 26, Number 1.

6. Stub article by JH4NMT (In Japanese)
   Japanese CQ, Sept. 1998

7. *Stub Filters Revisited*, G4SWX
   Radio Communication, Nov 1994
   Volume 70, No. 11.

8. *Low Band Dxing, Third Ed.*
   John Devoldere, ON4UN
   ARRL, 1999
   ISBN 0-87259-704-0
   Section 6.3.2.2 Using Coaxial Cable Stubs

9. *Electronic Filter Design Handbook. Third Ed.*
   Williams, Arthur B. and Fred J. Taylor
   McGraw-Hill, Inc. 1995
   ISBN 0-07-070441(hc)

7.0 SOURCES

1. Coax cable and connectors:

    1.1 Cable X-perts, Inc. www.cablexperts.com

    1.2 The RF Connection. www.therfc.com

2. Cable cutter:

    2.1 Techni-Tool. www.techni-tool.com

3. Coax stripper:

    3.1 Cable X-perts, Inc. www.cablexperts.com

4. Cable meter.

    4.1 Hykon Mfg Co.
    163 E. State St
    Alliance, OH 44601
    Model 1410

5. DDS Sweeper kit.

    5.1 Tibor Bece tbece@netspace.net.au www.netspace.net.au/~tbece

6. Shrink fit:

    6.1 Mouser Electronics. www.mouser.com

    6.2 Digi-Key. www.digikey.com

7. Additional information on the web:

    7.1 www.ifwtech.co.uk/g3sek/swxfiltr/swxfiltr.htm Information on VHF stubs.

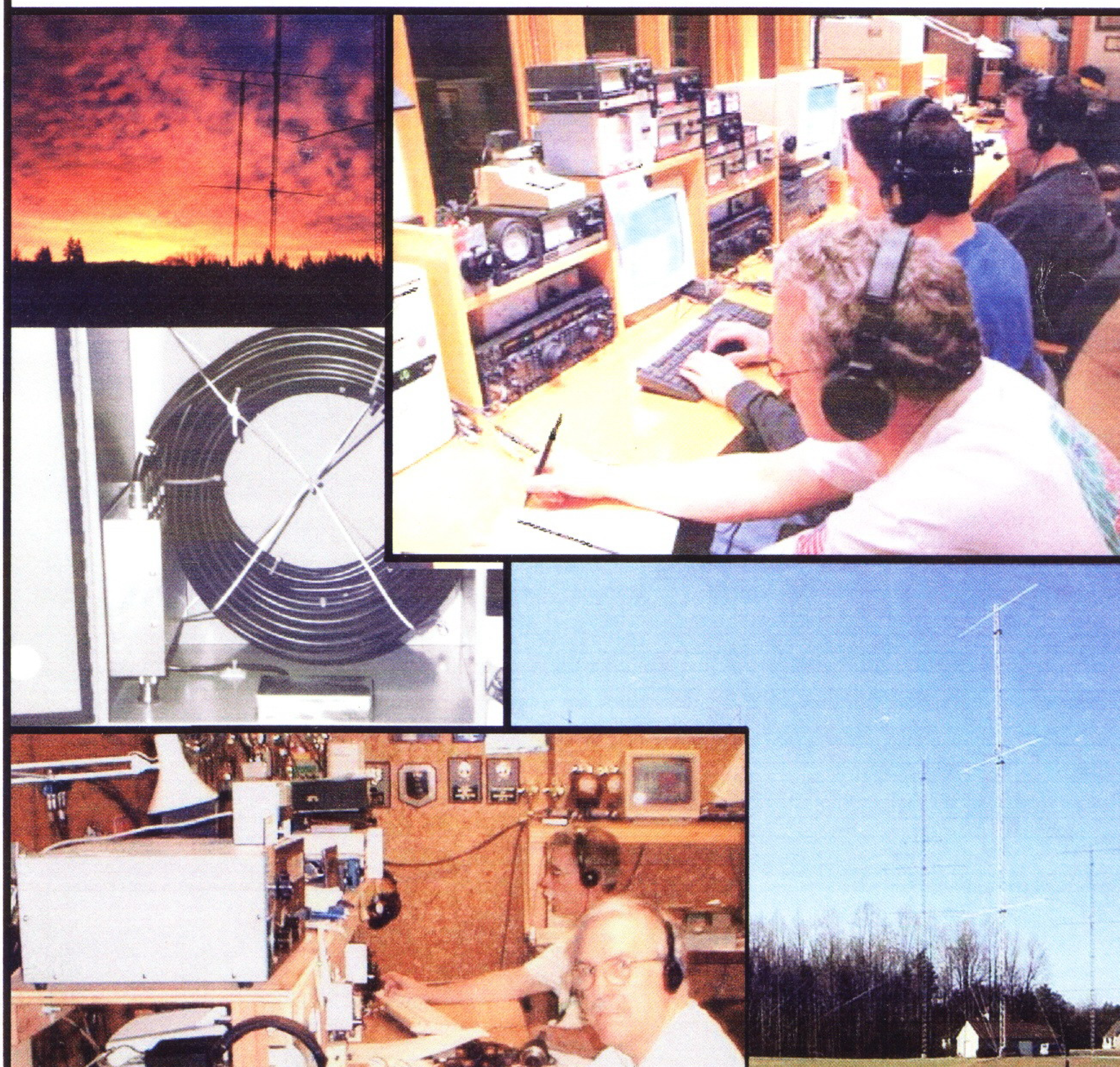
    7.2 www.k1ttt.net/technote/stubpair.html (Stub theory)

    7.3 www.qth.com/topten/stubs.htm (Commercially available stubs)

Managing Interstation Interference

Coaxial Stubs and Filters

W2VJN George Cutsogeorge



Comments from the reviewers:

In the past, only the M/M and M/S contest stations were confronted with the problem of dealing with extremely strong signals caused by the transmission of high-power transmitters in the close vicinity of receivers operating on other bands from the same QTH. We have recently seen the coming of the 2-radio single-Op stations, where similar problems of interstation interference are present. Solving these problems effectively in not an easy task, and profound understanding of the problem, as well as the possible ways to solve the problem are essential. George covers every imaginable aspect of the interference problem in this book and is complete in his coverage. Readers will learn how to tackle the problem and what it takes to solve it.

Well done, George!

John Devoldere, ON4UN

This book is a practical analysis of isolation and its importance in amateur radio station design. For the first time, a complete analysis of theory and practice is developed. This is important material for any amateur radio operator and absolutely essential for contesters with multi-radio stations.

Jim George, N3BB