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A LOW-PROFILE, REMOTE-TUNED DIPOLE ANTENNA FOR THE 30 TO 80 MHZ--ETC(U)

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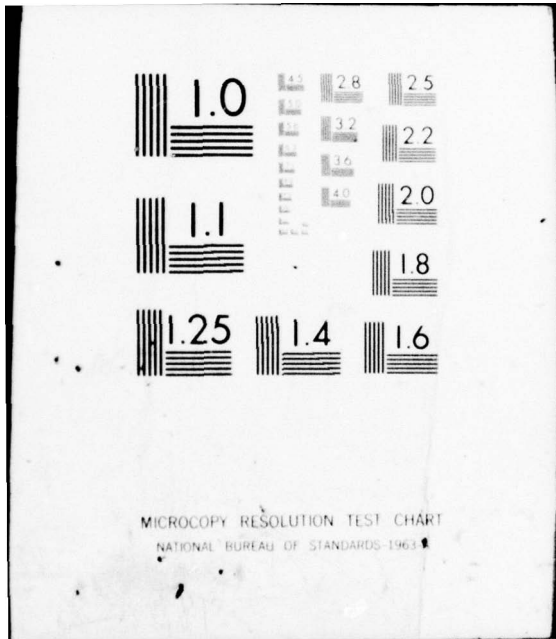
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A LOW-PROFILE, REMOTE-TUNED DIPOLE ANTENNA FOR  
THE 30 TO 80 MHz RANGE

D. V. Campbell

Communications/ADP Laboratory

April 1977

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A LOW-PROFILE, REMOTE-TUNED DIPOLE ANTENNA  
FOR THE 30 to 80 MHz RANGE

1. INTRODUCTION

The VHF range 30 to 88 MHz is used extensively for military radio FM communications. Antennas for VHF-FM are made in many different shapes and sizes, depending upon the intended application. Base station antennas include the RC-292 and OE-254 broadband omnidirectional antennas. These antennas are usually installed on thirty-foot masts; a large number of them are often collocated in a small area, thus compounding the problem of concealment.

Vehicular antennas include the AS-1729/VRC and the AS-2731/VRC. These particular antennas are center-fed and are ten- and six-feet long, respectively. In these antennas, the center-fed design reduces electrical interaction with the vehicle and thus results in nearly omnidirectional radiation pattern coverage, a highly desirable feature. The large height of these antennas, however, makes them prone to breakage.

Packset radio antennas, in contrast to resonant length antennas, are electrically and physically small. Antennas for packset radios are inefficient since, in addition to the power consumed in the tuning networks, power is absorbed by the operator's body, nearby objects, and the ground. Moreover, impedance matching is generally poor, because of the motion of the operator and his changing relationship to nearby objects. In addition, the packset antenna cannot be operated when detached from the radio; hence camouflage of the operator is difficult.

Under the sponsorship of USA Mobility Equipment R&D Command (MERADCOM), the Electronic Warfare Laboratory and Communications/Automatic Data Processing Laboratory have investigated techniques for reducing the visibility of standard VHF antennas.

Several approaches to the problem of camouflage of vehicular antennas have been studied at ECOM. Slot antennas [1], [2] and hybrid

- 
- [1] K. Ikrath, W. Kennebeck, D. Campbell, and C. DeSantis, "Slot coupled shelter of vehicle performing as VHF antenna," Research & Development Technical Report ECOM-4344, U. S. Army Electronics Command, Fort Monmouth, N. J., August 1975 (AD B007-088).
- [2] Kurt Ikrath, Paul Sexton, William Kennebeck, and Peter Pingitore, "VHF slot antennas on tanks," Research & Development Technical Report ECOM-4367, U. S. Army Electronics Command, Fort Monmouth, N. J., November 1975 (AD B007-878).

electromagnetic couplers (HEMACs), [3] for example, were found to reduce the antenna profile and at the same time cause the vehicle to act as a secondary radiator.

The investigation reported here was concerned with a portable VHF antenna. As originally conceived at ECOM, this low-profile VHF dipole antenna was intended primarily for use detached from a packset radio, and suspended in a tree or inside a building. In urban warfare, where the large resonant length antennas are difficult to deploy and camouflage, a small VHF antenna would be advantageous.

This new antenna should also provide satisfactory electrical performance when installed on vehicles/base stations/command posts. Whether the antenna should be developed for general purpose use or as a special item for particular applications has not yet been determined. In this report, the performance and electrical characteristics of this antenna will be considered in detail.

## 2. THEORY OF LOW-PROFILE, REMOTE-TUNED DIPOLE ANTENNA

### a. Configuration

The low-profile, remote-tuned dipole antenna is an electrically small center-fed dipole approximately one meter in length. This length corresponds to one-tenth of the wavelength at the lowest frequency (30 MHz) in the VHF-FM band. In contrast, resonant length antennas, such as the AS-1729/VRC, are much longer, e. g. , three meters in length.

The essential features of this antenna can be understood by referring to Fig. 1(A). The antenna is seen to consist of the dipole (conductors a and b), a variable capacitor  $C_T$ , an inductor  $L$  with self-capacitance  $C_s$  (undesirable), and a broadband cable choke. The inductor and variable capacitor are used to establish resonance. The cable choke consists of coaxial cable transmission line wound around a ferromagnetic core to create a high impedance with respect to current flowing on the outer shield. This cable choke electrically decouples the antenna from the transmission line. The decoupling feature, provided by the cable choke, minimizes the excitation of undesirable extraneous antenna current on the outer conductor of the transmission line and results in much more-uniform and -predictable radiation patterns and impedance characteristics. The cable choke also eliminates the need for a bulky ground plane or counterpoise at the base of the dipole.

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[3] Edward Shaffer and Kurt Ikrath, "Development of camouflaged vehicular VHF antennas," Research & Development Technical Report ECOM-4261, U. S. Army Electronics Command, Fort Monmouth, N. J., September 1974 (AD A000 659).

A schematic of the antenna appears in Fig. 1(B). In this representation, the antenna is considered to be located in free space; the cable choke and transmission line are ignored.

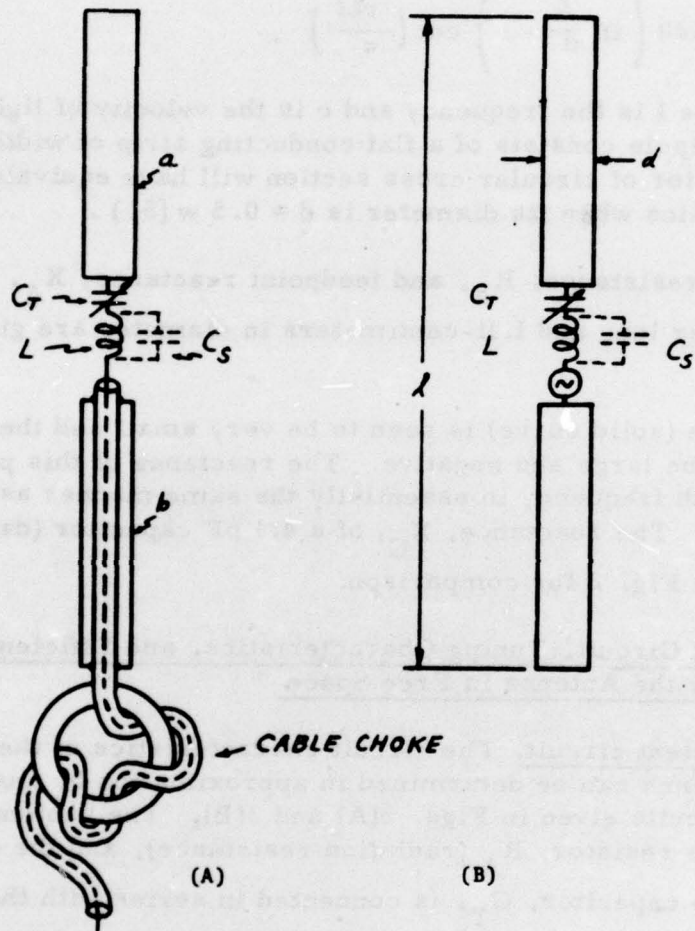


Fig. 1. Low-profile, remote-tuned dipole antenna.

b. Theoretical Impedance of the Antenna in Free Space

The resistive and reactive components of feedpoint impedance [4] of the electrically-short, center-fed, cylindrical dipole of length,  $l$ , and

[4] Edward C. Jordan, Electromagnetic Waves and Radiating Systems, Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1950.

diameter,  $d$ , in free space are:

$$R_A = 20 \left( \frac{\pi \ell f}{c} \right)^2 \quad (1)$$

and

$$X_A = -120 \left( \ln \frac{\ell}{d} - 1 \right) \cot \left( \frac{\pi \ell f}{c} \right) , \quad (2)$$

respectively. Here  $f$  is the frequency and  $c$  is the velocity of light in a vacuum. (If the dipole consists of a flat conducting strip of width  $w$ , a cylindrical conductor of circular cross section will have equivalent electrical characteristics when its diameter is  $d = 0.5 w$  [5] ).

The feedpoint resistance,  $R_A$ , and feedpoint reactance,  $X_A$ , for a VHF dipole 1-meter long and 1.11-centimeters in diameter are given in Fig. 2.

The resistance (solid curve) is seen to be very small and the reactance (dashed curve) to be large and negative. The reactance of this particular antenna varies with frequency in essentially the same manner as a 4.1 pF lumped capacitor. The reactance,  $X_C$ , of a 4.1 pF capacitor (dash-dot curve) is shown in Fig. 2 for comparison.

### c. Equivalent Circuit, Tuning Characteristics, and Efficiency Considerations for the Antenna in Free Space

(1) Equivalent circuit. The circuit characteristics of the low-profile dipole antenna can be determined in approximation by analysis of the equivalent circuits given in Figs. 3(A) and 3(B). The "antenna" is represented by the resistor,  $R_A$  (radiation resistance), and the capacitor,  $C_A$ . The variable capacitor,  $C_T$ , is connected in series with the antenna and the inductor,  $L$ . The resistance,  $R$ , accounts for power loss in the inductor. The capacitor,  $C_g$ , accounts for the undesirable (and mostly unavoidable) self-capacitance of the inductor which is caused by electrostatic coupling between turns and between the inductor and adjacent objects. It is well-known that this self-capacitance, or stray-capacitance, increases both the effective resistance and the effective inductance of the inductor [6] .

---

[5] John D. Kraus, Antennas, New York: McGraw-Hill Book Company, 1950.

[6] K. R. Sturley, Radio Receiver Design. Part I: Radio Frequency Amplification and Detection, London: Chapman & Hall, Ltd., 1953.

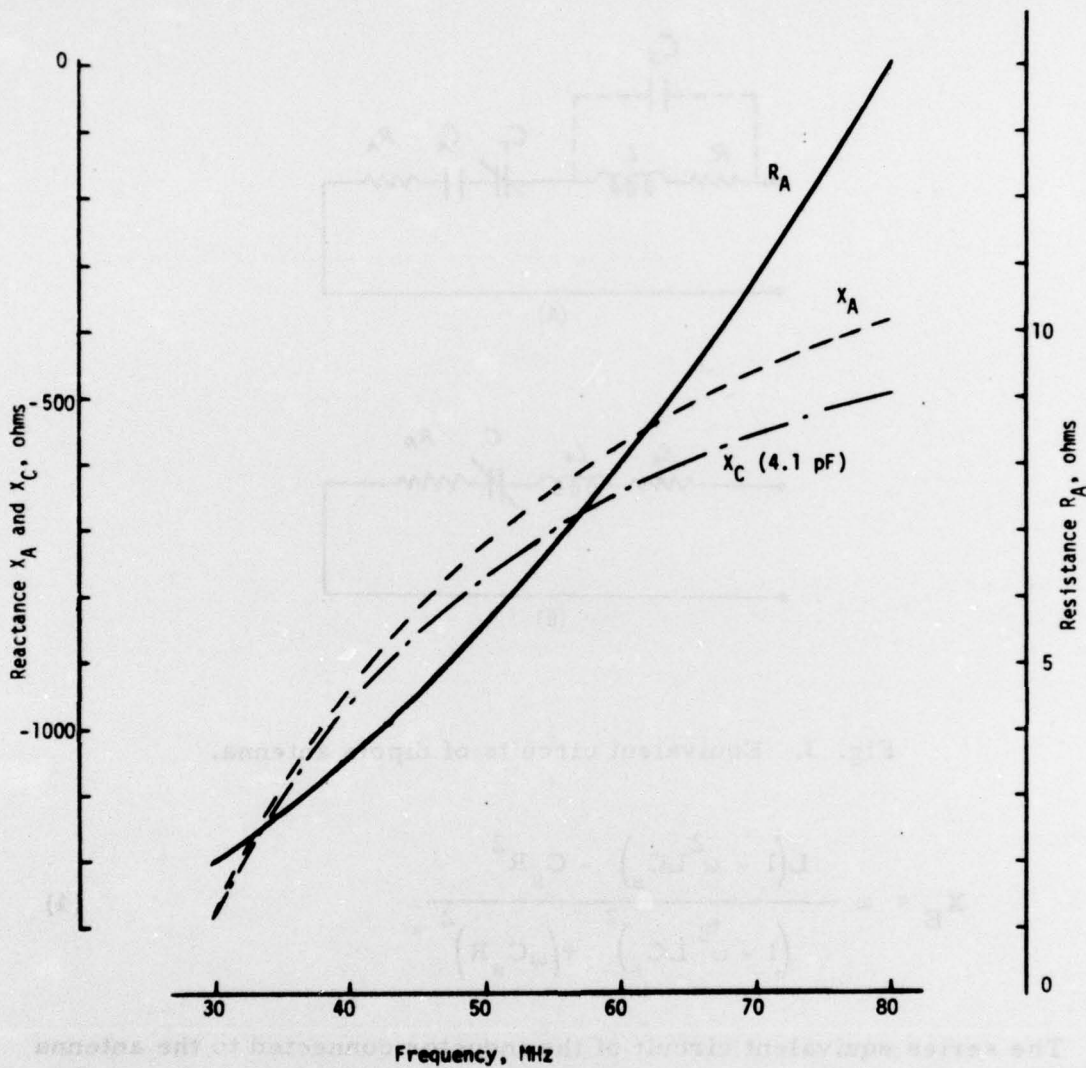


Fig. 2. Resistance and reactance at feed point of a dipole 1-meter long and 1.11-centimeters in diameter.

The equivalent series resistance,  $R_E$ , and equivalent series reactance,  $X_E$ , of the inductor are found to be:

$$R_E = \frac{R}{(1 - \omega^2 LC_s)^2 + (\omega C_s R)^2} \quad (3)$$

and

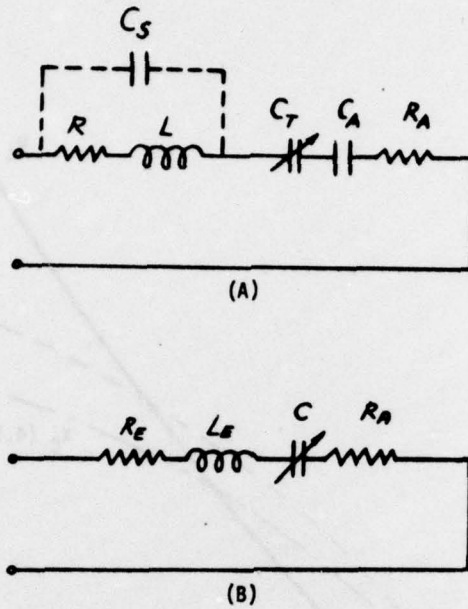


Fig. 3. Equivalent circuits of dipole antenna.

$$X_E = \omega \frac{L(1 - \omega^2 LC_s) - C_s R^2}{(1 - \omega^2 LC_s)^2 + (\omega C_s R)^2} \quad (4)$$

The series equivalent circuit of the inductor connected to the antenna is shown in Fig. 3(B). The expressions for the equivalent series resistance and equivalent series reactance can be stated in a different form by substituting  $C_s R = 1/\omega_0 Q$ ,  $C_s R^2/L = 1/Q^2$ , and  $\omega_0 = 1/\sqrt{LC_s}$  into (3) and (4). After these substitutions are made, we find that:

$$R_E = \frac{R}{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2 + \left(\frac{\omega}{\omega_0 Q}\right)^2} \quad (5)$$

and

$$X_E = \frac{\omega L \left( 1 - \frac{\omega^2}{\omega_0^2} - \frac{1}{Q^2} \right)}{\left( 1 - \frac{\omega^2}{\omega_0^2} \right)^2 + \left( \frac{\omega}{\omega_0 Q} \right)^2} \quad (6)$$

In these expressions,  $\omega_0$  is the frequency at which the inductor resonates with its self-capacitance, and  $Q = \omega_0 L/R$  is the  $Q$  of the inductor.

If the self-capacitance is small and  $Q$  is large, the effective series resistance and effective series inductance are then:

$$R_E = \frac{R}{\left( 1 - \omega^2 LC_s \right)^2} = \frac{R}{\left( 1 - \frac{\omega^2}{\omega_0^2} \right)^2} \quad (7)$$

and

$$L_E = \frac{L}{1 - \omega^2 LC_s} = \frac{L}{1 - \frac{\omega^2}{\omega_0^2}} \quad (8)$$

and the effective  $Q$  of the inductor is

$$Q_E = \frac{\omega L E}{R_E} = \frac{\omega L}{R} \left( 1 - \omega^2 LC_s \right) = Q \left( 1 - \frac{\omega^2}{\omega_0^2} \right). \quad (9)$$

It is apparent that the self-capacitance can increase both the effective resistance and effective inductance significantly. It will be shown that such an increase in the effective resistance will be accompanied by a corresponding decrease in antenna efficiency.

(2) Resonance condition. Resonance is established in the antenna circuit (Fig. 3(B)) when  $\omega L_E = 1/\omega C$ , where  $C$ , the effective capacitance

of  $C_T$  and  $C_A$  connected in series, is given by

$$C = \frac{C_A C_T}{C_A + C_T} \quad (10)$$

Upon using (8), we find that

$$\frac{\omega L}{1 - \omega^2 L C_s} = \frac{1}{\omega C} \quad (11)$$

and that the resonance frequency is

$$\omega = \frac{1}{\sqrt{L(C + C_s)}} \quad (12)$$

Substitution of (12) into (7), (8), and (9) yields,

$$R_E = R \left( 1 + \frac{C_s}{C} \right)^2 \quad (13)$$

$$L_E = L \left( 1 + \frac{C_s}{C} \right) \quad (14)$$

and

$$Q_E = \frac{Q}{1 + \frac{C_s}{C}} \quad (15)$$

Expressions (13) through (15) are interesting and useful because they show how the self-capacitance,  $C_s$ , and the capacitance,  $C$ , affect the antenna efficiency and tuning characteristics.

(3) Tuning characteristics. The tuning range of the antenna can be determined by alternate substitution of  $C_{Max}$  and  $C_{Min}$  for  $C$  in (12), where

$$C_{Max} = \frac{C_A C_T Max}{C_A + C_T Max} \quad (16)$$

and

$$C_{\text{Min}} = \frac{C_A C_{T \text{ Min}}}{C_A + C_{T \text{ Min}}} \quad (17)$$

Thus, the ratio of the upper frequency,  $f_u$ , to the lower frequency,  $f_l$ , is

$$\frac{f_u}{f_l} = \sqrt{\frac{C_{\text{Max}} + C_s}{C_{\text{Min}} + C_s}} \quad (18)$$

It is thus apparent that the self-capacitance,  $C_s$ , causes a decrease in the tuning range. In (16),  $C_{T \text{ Max}}$  denotes the maximum value of the tuning capacitor,  $C_T$ . Likewise, in (17),  $C_{T \text{ Min}}$  denotes the minimum value of the tuning capacitor,  $C_T$ .

The range of variation of the capacitor,  $C_T$ , deserves consideration because  $C_T$  affects the tuning range of the antenna significantly. Obviously, it is desirable to use a variable capacitor with the smallest possible value of minimum capacitance,  $C_{T \text{ Min}}$ , because the tuning range will then be increased. Ideally,  $C_{T \text{ Min}} \ll C_A$ , for then  $C_{\text{Min}} \approx C_{T \text{ Min}}$ . The maximum capacitance,  $C_{T \text{ Max}}$ , of the variable capacitor should be much greater than the antenna capacitance,  $C_{T \text{ Max}} \gg C_A$ , so that  $C_{\text{Max}} \approx C_A$ . Under these ideal conditions, the tuning range of the antenna is

$$\frac{f_u}{f_l} \approx \sqrt{\frac{C_A + C_s}{C_{T \text{ Min}} + C_s}} \quad (19)$$

Just how large  $C_{T \text{ Max}}$  should be depends of course on the value of the antenna capacitance,  $C_A$ . It is useful to plot the variation of  $C$  versus  $C_T$  because it shows clearly the practical range of variation for  $C_T$ . The value of  $C$  corresponding to  $C_T$  is shown in Fig. 4 for several values of antenna capacitance,  $C_A$ . It is seen that the greatest variation in  $C$  occurs between the minimum value of  $C_T$  and where  $C_T$  is five- to ten-times greater

than  $C_A$ . For values of  $C_T > 10 C_A$ , the corresponding variation in  $C$  is small. In terms of tuning characteristics of the antenna, there is no advantage in using large values for  $C_{T \text{ Max}}$  since the rate of tuning decreases significantly where  $C_T > 10 C_A$ . In the case of the subject antenna ( $C_A \approx 4 \text{ pF}$ ), it is practical to use a variable capacitor  $C_T$  such that  $C_{T \text{ Max}} \leq 50 \text{ pF}$ . In addition, the minimum value,  $C_{T \text{ Min}}$  of the variable capacitor, should be as small as possible.

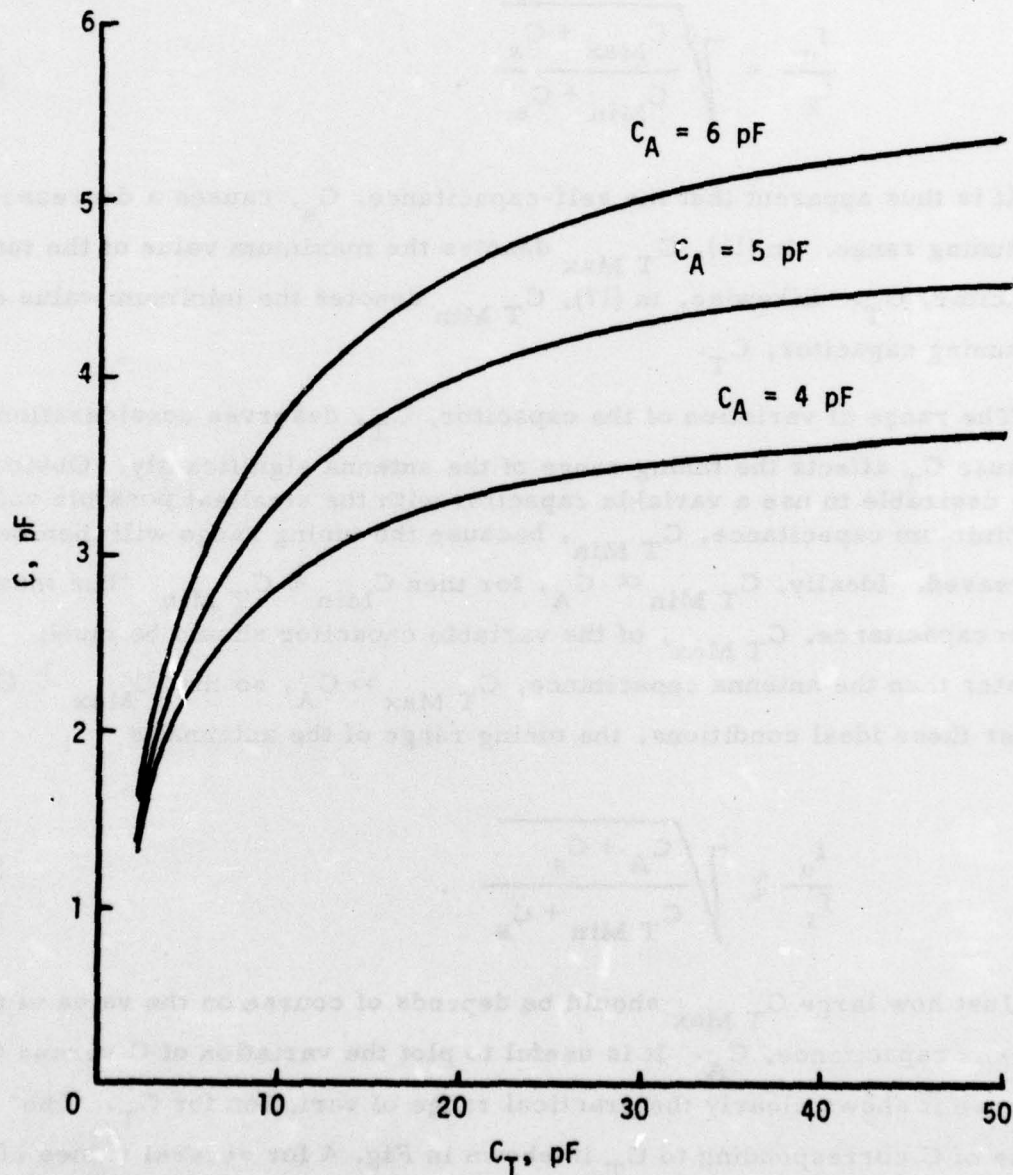


Fig. 4. Effective capacitance versus tuning capacitance (antenna capacitance as parameter).

Formula (18) suggests that it may not be possible to cover the entire VHF-FM range in a single band. However, coverage of the entire VHF-FM range can be obtained by switching inductors having different values into the circuit to provide overlapping bands. For example, if seven bands were used to cover the frequency range 30 to 88 MHz, then in each band the ratio of the upper to the lower frequency would be

$$\frac{f_u}{f_l} = \left( \frac{f_{\text{Max}}}{f_{\text{Min}}} \right)^{1/N} = \left( \frac{88}{30} \right)^{1/7} = 1.166 .$$

Thus, the first band would extend from 30 to 34.98 MHz; the second, from 34.98 to 40.79 MHz; and so on. Of course, some frequency overlap should be provided.

(4) Theoretical efficiency. The efficiency,  $\eta$ , of the antenna in free space can be determined from the ratio of radiated power to total power:

$$\begin{aligned} \eta &= \frac{\text{Power Radiated}}{\text{Total Power}} = \frac{\text{Power Radiated}}{\text{Power Radiated} + \text{Power Dissipated}} \\ &= \frac{R_A}{R_A + R_E} . \end{aligned}$$

The use of (9), (11), (13), and (14) results in

$$\eta = \frac{R_A}{R_{IN}} = \frac{R_A}{R_A + \frac{1}{\omega C Q} \left( 1 + \frac{C_s}{C} \right)} . \quad (20)$$

The theoretical efficiency (20) of the experimental antenna (whose dimensions are given in Section 2. B) is shown versus frequency in Figure 5. The antenna capacitance was 4 pF, the variable tuning capacitor ranged from 5 to 50 pF, and the Q of the inductors was 200. The efficiency is shown for two different values of self-capacitance,  $C_s$ , of the inductor: 1 and 3 pF.

It can be seen that the efficiency and the tuning range for each band is reduced significantly by the self-capacitance.

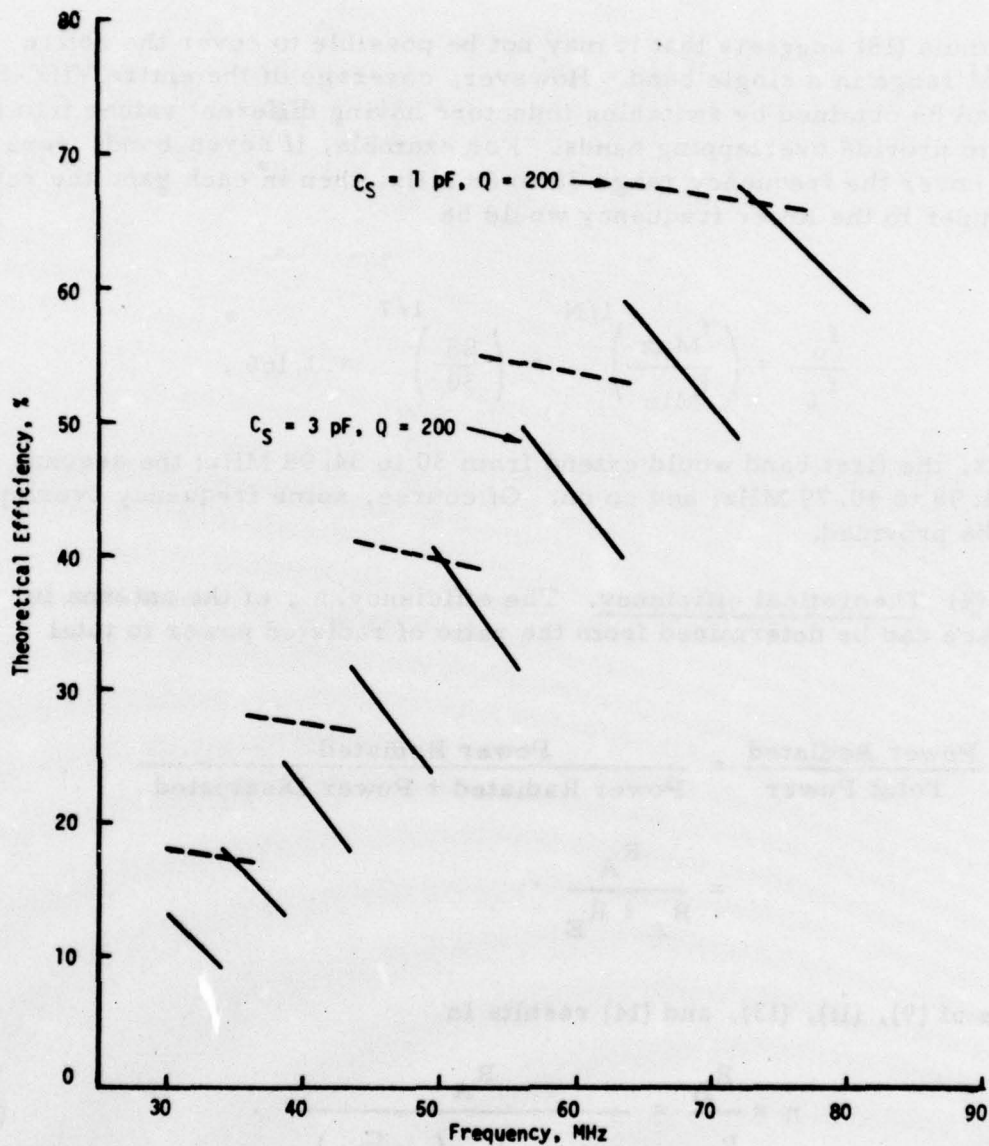


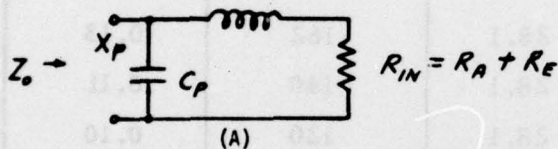
Fig. 5. Theoretical efficiency of experimental antenna.

d. Antenna Input Resistance and Impedance Matching Networks

The input resistance of the antenna is given by the denominator of (20). In order to maximize the transfer of power,  $R_{IN}$  should be matched to the characteristic impedance,  $Z_0$ , of the transmission line. If the antenna resonating circuit is efficient, the input resistance,  $R_{IN}$ , will be

small compared to  $Z_o$ , and an impedance matching network will be required between the antenna and the transmission line. The well-known L-networks shown in Figs. 6(A) and 6(B) can be used to match the (low) input resistance,  $R_{IN}$ , to the characteristic impedance,  $Z_o$ , of the transmission line. The transformation is effected by the parallel reactance,  $X_p$ , whose value is

$$X_p = Z_o \sqrt{\frac{Z_o}{R_{IN}} - 1} \quad (21)$$



To obtain the proper transformation,  $X_p$  must be dimensioned in accordance with (21), and the antenna must be detuned slightly from resonance. If the antenna is detuned on the "inductive" side of resonance,  $X_p$  will be "capacitive" (Fig. 6(A)); if the antenna is detuned on the "capacitive" side of resonance,  $X_p$  will be "inductive" (Fig. 6(B)).

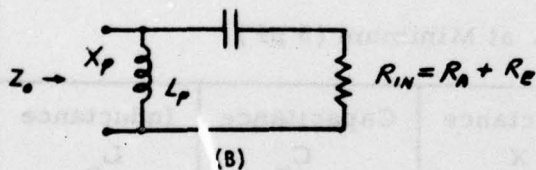


Fig. 6. Impedance matching networks.

It is interesting to determine the theoretical values of  $X_p$  and the corresponding values of  $C_p$  and  $L_p$  for the experimental antenna. These values are given in Table 1 for the lowest and highest frequency in each band, together with the input resistance for the assumed case where the stray capacitance is 2 pF and the Q is 200. It is seen that the required value for the parallel inductance,  $L_p$ , changes very little over the entire VHF range. The required value for the parallel capacitance,  $C_p$ , varies somewhat with frequency, but in each band the average value can be used for  $C_p$ . The antenna with the parallel capacitor,  $C_p$ , is shown in Fig. 7 to illustrate the use of the L matching network.

Impedance match can also be obtained by means of a broadband transformer inserted between the antenna and the transmission line. A perfect match will not be obtained at all frequencies, but the mismatch may be tolerable.

Table 1. Input Resistance and Values of Impedance Matching Elements used in Experimental Low-Profile Dipole Antenna (Assumed self-capacitance:  $C_s = 2$  pF)

(Assumed Q:  $Q = 200$ )

Tuning Capacitor, $C_T$ , at Maximum (50 pF)					
Band (No.)	Frequency $f_l$ (MHz)	Resistance $R_{IN}$ (ohms)	Reactance $X_P$ (ohms)	Capacitance $C_P$ (pF)	Inductance $L_P$ ( $\mu$ H)
1	30.0	13	29.6	179	0.16
2	34.9	12	28.1	162	0.13
3	40.5	12	28.1	140	0.11
4	47.1	12	28.1	120	0.10
5	54.7	12	29.6	98	0.09
6	63.6	14	31.0	80	0.08
7	73.9	17	36.0	60	0.08

Tuning Capacitor, $C_T$ , at Minimum (5 pF)					
Band (No.)	Frequency $f_u$ (MHz)	Resistance $R_{IN}$ (ohms)	Reactance $X_P$ (ohms)	Capacitance $C_P$ (pF)	Inductance $L_P$ ( $\mu$ H)
1	34.9	22	44.3	102	0.20
2	40.5	20	40.8	96	0.16
3	47.1	19	39.0	86	0.13
4	54.7	19	39.0	74	0.11
5	63.6	20	40.8	61	0.10
6	73.9	21	42.6	51	0.09
7	85.9	24	48.0	39	0.09

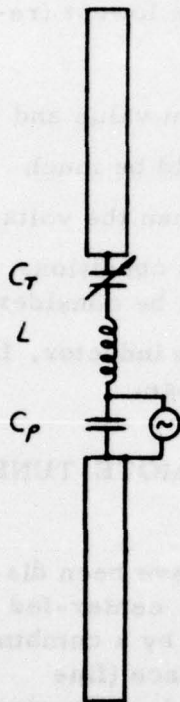


Fig. 7. Dipole antenna with impedance matching capacitor,  $C_p$ .

### e. Power and Voltage Considerations

The electrically-small dipole antenna sustains high voltages and large current, even when transmitting at moderate power levels.

The antenna current and the voltage across the various components can be calculated as follows. Assume the antenna is resonated and matched. The input power,  $P_{IN}$ , is dissipated in the tuning circuit and radiated by the antenna. The losses and radiation are accounted for by the resistance,  $R_{IN}$ , which is known. It follows that the antenna current,  $I_A$ , is given by

$$I_A = \sqrt{\frac{P_{IN}}{R_{IN}}} \quad (22)$$

The voltage across the antenna "capacitance,"  $C_A$ , is

$$V_A = \frac{I_A}{\omega C_A} \quad (23)$$

and the voltage across the variable tuning capacitor,  $C_T$ , is

$$V_{CT} = I_A \cdot \frac{1}{\omega C_A} \cdot \frac{C_A}{C_T} \quad (24)$$

Obviously, the voltage across  $C_T$  depends upon the setting of  $C_T$  and will be at a maximum (minimum) when  $C_T$  is at minimum (maximum) capacitance.

To illustrate orders of magnitude, assume that the frequency is 30 MHz, the input resistance is 13 ohms, and the antenna reactance is -1300 ohms (see Fig. 2 and Table 1).

It follows from (22) that when the input power is  $P_{IN} = 50$  watts, the antenna current,  $I_A$ , is 1.96 amperes, and the voltage (23) across the antenna "capacitance" (4 pF) is 2550 volts. If it is assumed that the variable tuning capacitor,  $C_T$ , is set at its maximum value of 50 pF, it follows that

the voltage across  $C_T$  (24) will be 204 volts. The above calculations apply, for example, to the case where the antenna is resonated at the lowest frequency in Band 1 (see Table 1).

If the variable tuning capacitor,  $C_T$ , is set at its minimum value and all other conditions are the same, the voltage across  $C_T$  would be much larger. For example, if the minimum value of  $C_T$  is 2 pF, then the voltage across the tuning capacitor will be 5100 volts for the assumed conditions. The voltage rating of the variable tuning capacitor,  $C_T$ , must be considered carefully in designing this type tuning circuit. Of course, the inductor,  $L$ , must also be carefully designed because it sustains high voltage.

### 3. EXPERIMENTAL MODELS OF THE LOW-PROFILE, REMOTE-TUNED DIPOLE ANTENNA

The essential features of the low-profile dipole antenna have been discussed. The antenna was described as an electrically-short, center-fed dipole which is tuned to resonance at the operating frequency by a combination of fixed inductors (coarse tuning) and a variable capacitance (fine tuning). The number of fixed inductors equals the number of (overlapping) bands. A high impedance broadband cable choke at the base of the dipole eliminates the need for a counterpoise or ground plane and thus reduces interaction of the transmission line and antenna.

#### a. Features of the Five Experimental Models

Five different antennas were constructed, each incorporating significant design changes. These changes were made to optimize the characteristics of the antenna with respect to tuning, efficiency, impedance match, and operational convenience. The features of the five antennas are given in Table 2. Simplified schematics of the antennas appear in Fig. 8. Antenna No. 1 utilized a tuning circuit connected in parallel with the antenna feed point. Theoretical analysis (see Appendix) shows that the low efficiency (1%) of this antenna was due, in part, to the use of the parallel tuning circuit.

Antenna No. 2 utilized a series tuning circuit and a manually-operated bandswitch. The low efficiency of Antenna No. 2 was attributed to power loss in the cable choke, which was subsequently redesigned. The new cable choke was incorporated in Antenna No. 3, and a 10-fold increase in efficiency resulted.

Antenna Nos. 4 and 5 were developed to provide the convenience of remotely-controlled coarse tuning and fine tuning; built-in impedance matching circuits were provided to reduce VSWR. Antenna No. 5 uses, in addition, a variable tuning capacitor designed to withstand 10 kilovolts. Hence, the antenna can be operated with vehicular radios at the 40- to 50-watt power level.

Table 2. Significant Features of the Five Experimental Models of the Low-Profile, Remote-Tuned Dipole Antenna.

Antenna Model No.	Tuning Circuit	Tuning Capacitor	Cable Choke	Switching Method
1	Parallel	Standard	Cylindrical	Not needed
2	Series	Standard	Cylindrical	Manual
3	Series	Standard	Ferrite Core	Manual
4	Series	Standard	Ferrite Core, Multicoil	Electromechanical, Remote
5	Series	High Voltage	Ferrite Core, Multicoil	Electromechanical, Remote

Antenna Model No.	No. of Bands	Tuning Range (MHz)	Impedance Matching	Maximum VSWR	Minimum Efficiency (percent)	Estimated Power Rating (watts)
1	1	30-76	Yes	3.0	1	5
2	5	30-64	No	3.8	1	5
3	5	30-64	No	3.8	12	5
4	7	30-76	Yes	2.2	10	5
5	7	30-80	Yes	2.0	*	50

\*Not measured, estimated to be 10%.

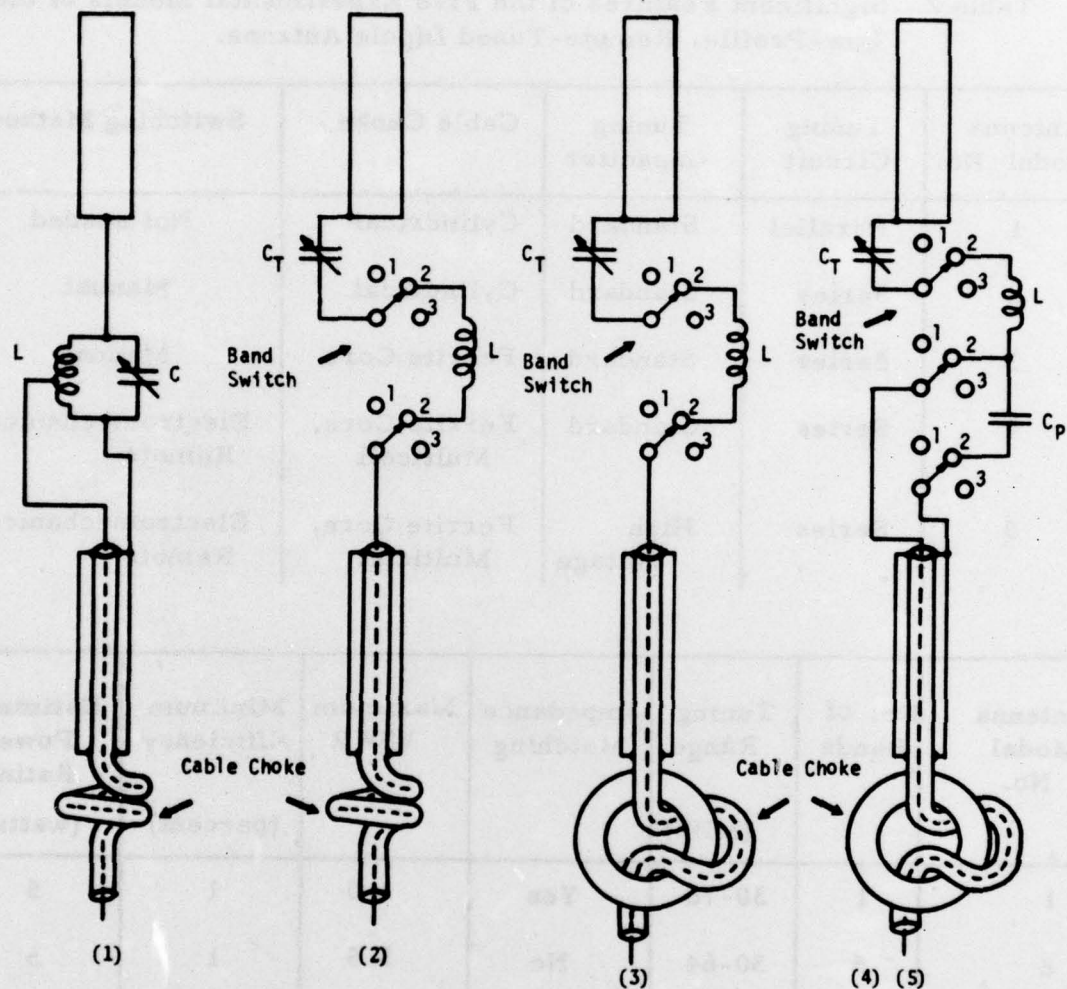


Fig. 8. Schematics of experimental low-profile, remote-tuned dipole antenna.

The schematic of Antenna Nos. 4 and 5 given in Fig. 9 shows the electromechanical devices which activate the bandswitch and fine tuning capacitor. The remote control unit is shown schematically in Fig. 10. The tuning of the antenna is remotely controlled by manually selecting the proper band and by manually adjusting the fine tuning controls until resonance is established. Resonance is indicated by a meter, connected in series with the transmission line, which displays the reflected power. A photograph of Antenna No. 4 is shown in Fig. 11.

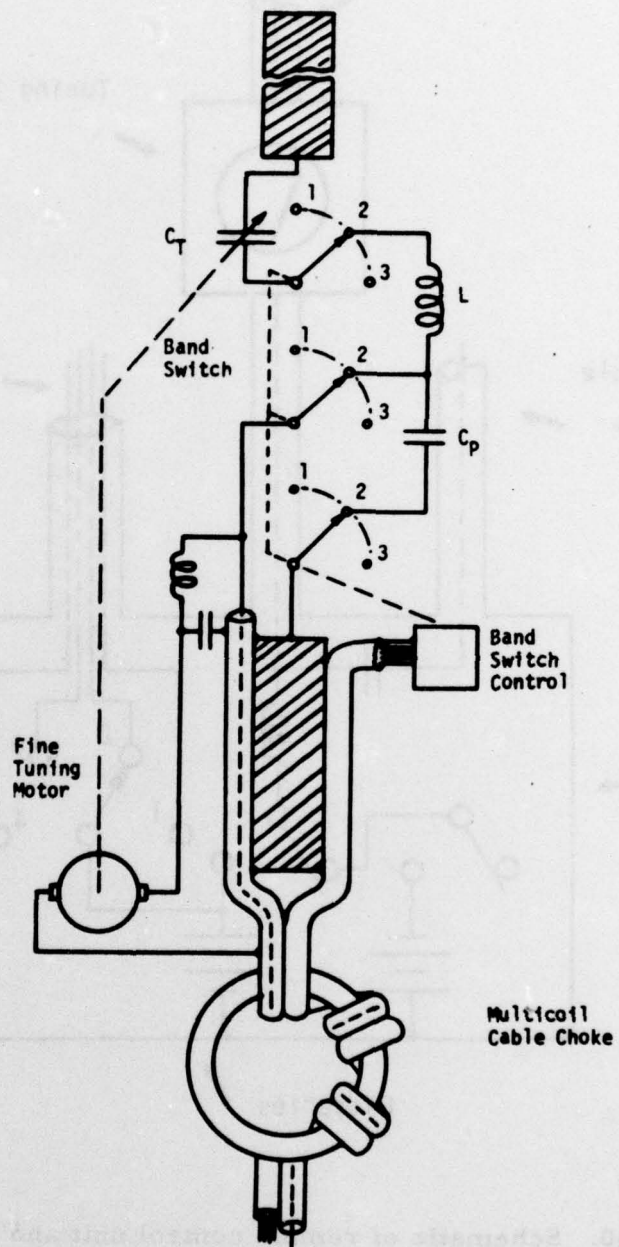


Fig. 9. Schematic of experimental low-profile, remote-tuned dipole antenna (Nos. 4 and 5) showing details of electromechanical devices.

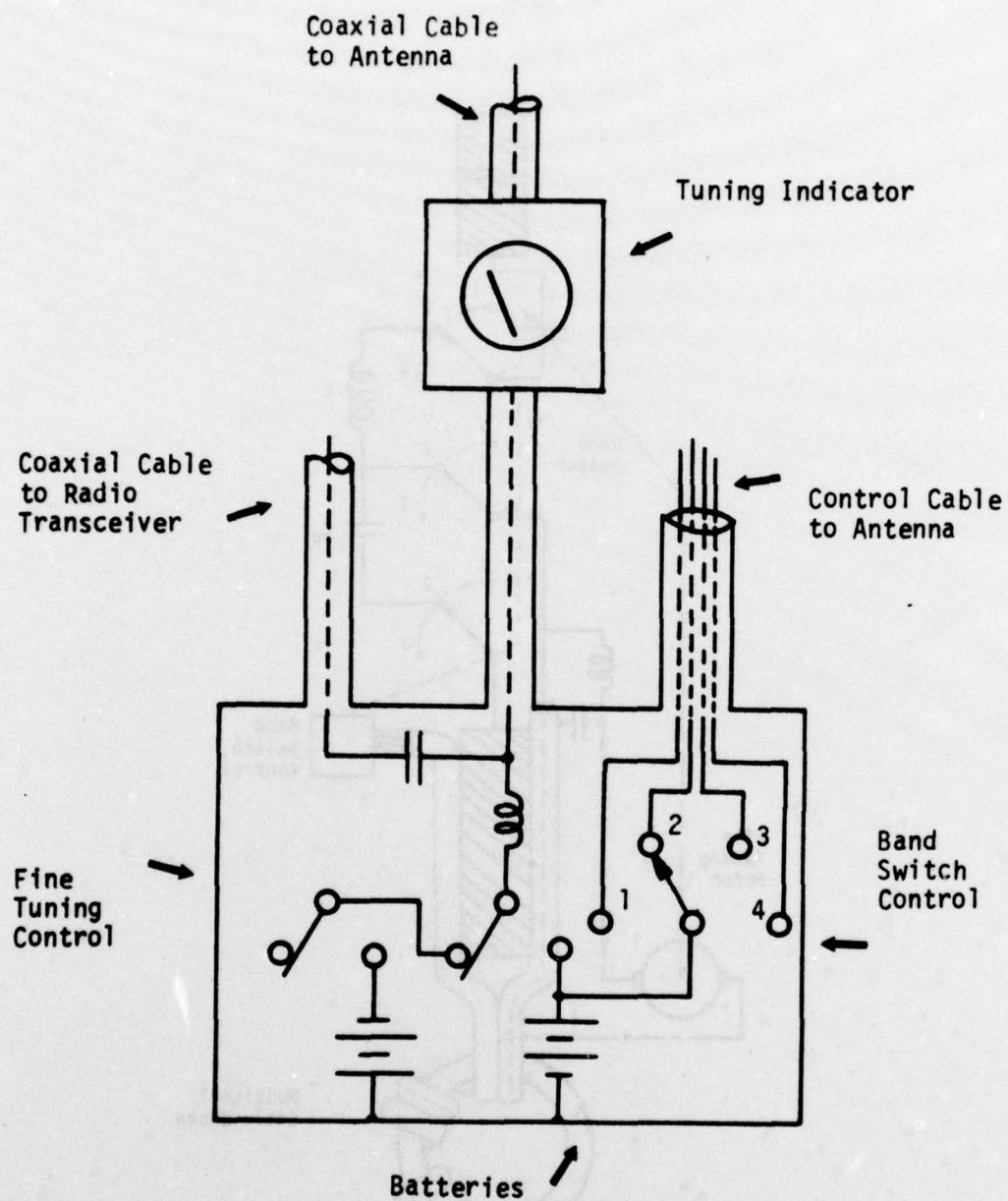


Fig. 10. Schematic of remote control unit and tuning indicator for Antenna Nos. 4 and 5.



Fig. 11. Antenna No. 4

b. Experimental Results

(1) Tuning range and VSWR. When switched to the proper band, Antenna No. 5 could be resonated at any frequency between 30 and approximately 80 MHz. Adjacent bands have overlapping frequencies. The VSWR, which is a measure of the quality of the impedance match, was less than two at all frequencies at which the antenna was resonated.

(2) Efficiency relative to standard whip antenna. The efficiency of the low-profile antenna (Antenna No. 4) was determined relative to the standard vehicular whip antenna AS-1729/VRC (reference antenna). The test antenna and the reference antenna were installed, in turn, above a ground plane two-meters square, and the input power and the field intensity were measured.

The efficiency,  $\eta_1$ , of the test antenna is related to the efficiency,  $\eta_2$ , of the reference antenna by the expression:

$$\frac{\eta_1}{\eta_2} = \left( \frac{E_1}{E_2} \right)^2 \left( \frac{V_2}{V_1} \right)^2 \frac{G_2}{G_1} .$$

Here,  $E_1(E_2)$  is the received field intensity,  $V_1(V_2)$  is the applied input voltage, and  $G_1(G_2)$  is the input conductance of the respective antennas. All these quantities are measurable.

The absolute efficiency of the standard whip antenna was unknown. However, its efficiency was assumed to be nearly 100% because the whip is near resonant length.

The measured field intensity (in dB) of Antenna No. 4 relative to the reference antenna, AS-1729, is given in Fig. 12. The measured relative efficiency expressed in percent appears in Fig. 13. The results given in Fig. 5 (theoretical efficiency) and Fig. 13 (measured efficiency) are in rather good agreement in the frequency range 30 to 54 MHz. However, above 54 MHz, the measured efficiency was apparently lower than predicted. The difference is attributed, in part, to errors introduced by interfering signals, e.g., TV signals, and the non-ideal behavior of the antenna test range and the ground plane. For these reasons, the true efficiency of the low-profile antenna at frequencies above 54 MHz is probably substantially better than the measurements indicate.

It should also be recalled that when the theoretical efficiency was determined, free-space conditions were assumed and the effect of the cable choke was ignored. Nevertheless, the considerable difference between the

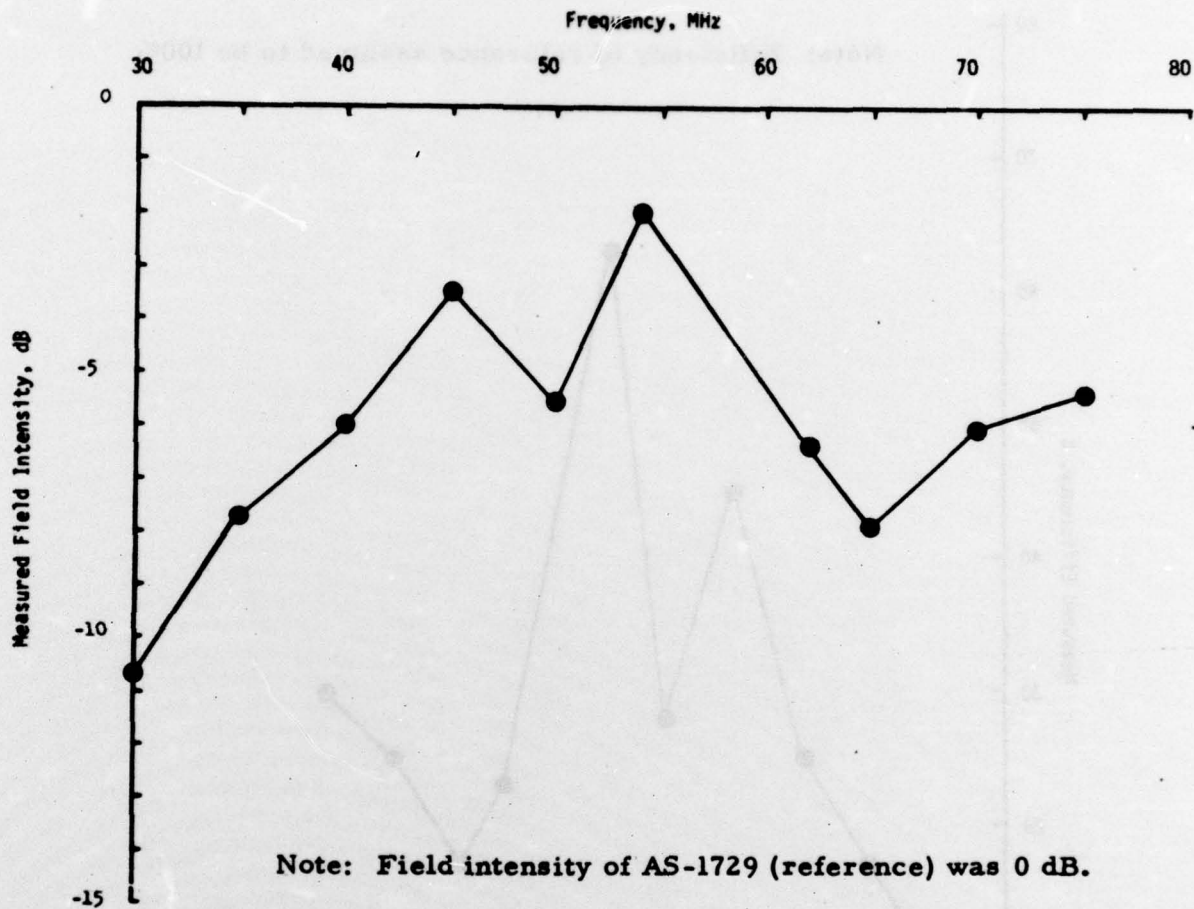


Fig. 12. Measured field intensity of Antenna No. 4 relative to AS-1729 (reference).

theoretical and the measured efficiency at the higher frequencies should be further investigated and perhaps alternate methods (such as Wheeler's method [7] ) for measuring the antenna efficiency evaluated.

[7] H. A. Wheeler, "The radiansphere around a small antenna," Proc. IRE, August 1959, pp. 1325-1331.

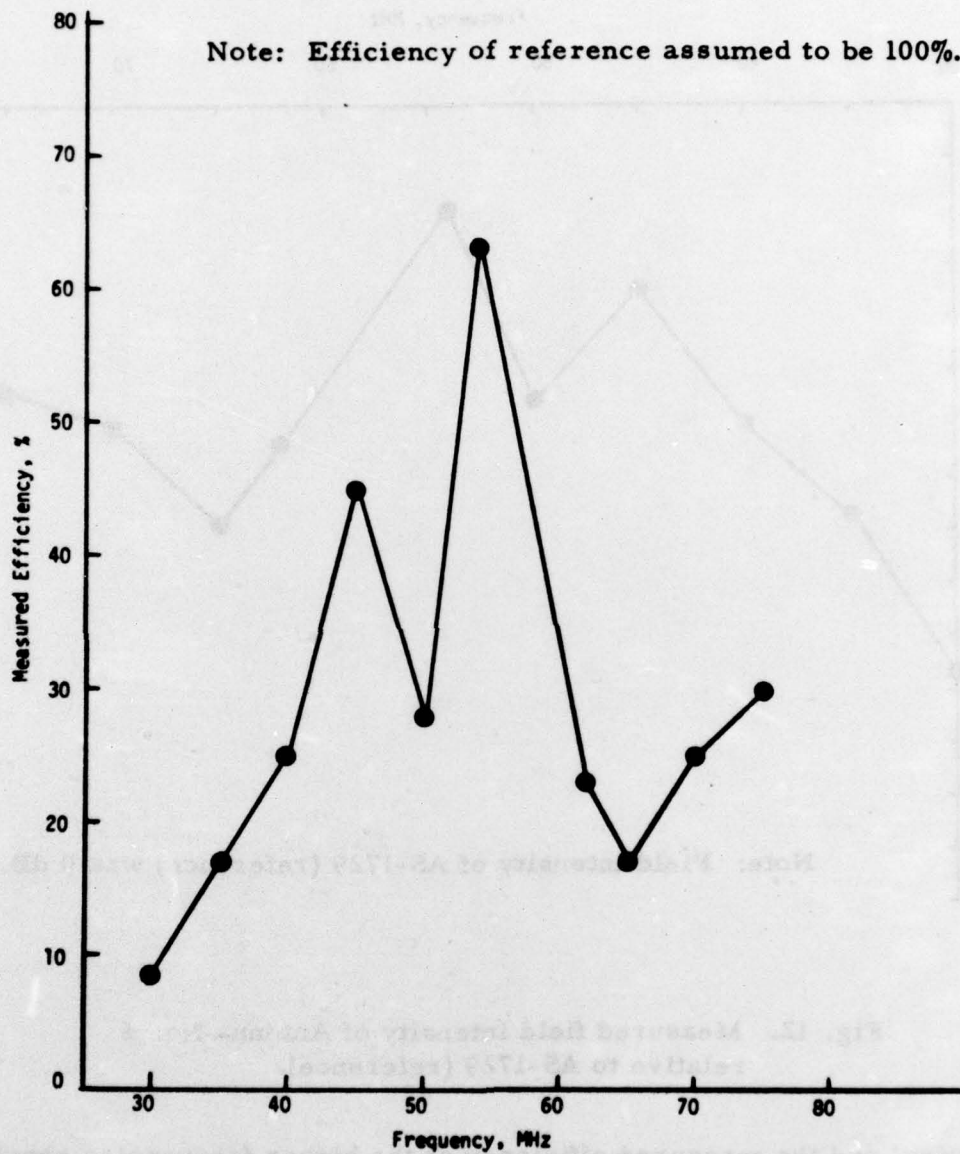


Fig. 13. Measured efficiency of Antenna No. 4 relative to AS-1729 (reference).

(3) Communications range achieved between base station and mobile unit. Tests were performed to determine the maximum communication range between a mobile unit and the base station equipped with AN/VRC-12 Radios. The mobile terminal was provided with a standard AS-1729 Whip Antenna and the fifth version of the experimental low-profile dipole antenna. A broad-band biconical VHF antenna (Type OE-254) mounted on a 9-meter mast was used as the base station antenna.

Communications were established at two- to three-mile intervals over a distance of 34 km. The operating frequency was 49.9 MHz and the terrain was comparatively flat. Test results are given in Table 3. At these distances, the standard whip and the low-profile dipole antenna provided almost the same quality communications. The standard whip antenna, because of its greater efficiency, provided slightly better quality communications at distances in excess of 34 km.

#### c. Applications for the Low-Profile, Remote-Tuned Dipole Antenna

(1) Antenna suspended in a tree. To minimize the risk of visual detection, the antenna can be detached from the packset radio and deployed in a tree, as illustrated in Fig. 14. In this operating mode, the antenna can be located approximately 30 meters from the radio operator, enabling him to take full advantage of camouflage. Because the tuning of the antenna is remote-controlled, detuning effects caused by nearby tree branches can be compensated for.

(2) Multiple antennas collocated at command posts. When a number of the low-profile antennas are installed in a confined area and tuned to different frequencies, cross talk interference is not troublesome. This follows because low-profile antennas of the type described here have narrow instantaneous bandwidth, which enables them to discriminate against adjacent channel interference. Consequently, these antennas are ideal for use at command posts and in re-transmission systems where cross talk interference is often encountered.

(3) Antenna for vehicular use. The communications range tests prove that the low-profile dipole antenna performs well as a low-silhouette vehicular antenna. Due to its low height, it is less vulnerable to damage than the standard whip antennas currently used. In addition, because it is center fed, the antenna will not interact strongly with the vehicle platform; consequently, radiation-pattern distortion will be minimal.

#### 4. CONCLUSIONS

Experimental low-profile, remote-tuned VHF dipoles have been investigated and two operational antennas approximately 1-meter in length have been developed. The theory of these antennas and experimental verification,

for the most part, are in good agreement. Although simple, the theory suffices to explain the overall characteristics of the antenna.

Table 3. Results of Communications Range Test Conducted Between Base Station\* (Wayside, N. J.) and Mobile Unit\*\* (Wayside to Toms River, N. J.). (Base station and mobile unit equipped with AN/VRC-12 Radios operating at 49.9 MHz.)

Range (km)	AS-1729 Antenna (reference)		Experimental Low-Profile Antenna No. 5	
	Clarity†	Strength††	Clarity†	Strength††
10	5	9	5	9
14	5	6	5	6
19	5	5	5	5
24	5	5	5	4
27	5	5	5¶	4¶
34 (Toms River)	5	5	5¶	6¶

\* Base station equipped with broadband biconical VHF antenna (Type OE-254) on 9-meter mast.

\*\* Mobile unit equipped with AS-1729 Antenna (reference) and fifth version of the experimental low-profile dipole antenna.

† Clarity of signal, scale 1 to 5.

†† Strength of signal, scale 1 to 9.

¶ Squelch off.

Because the antenna is center fed and is isolated at its base, it can be operated without a counterpoise or ground plane. When installed on a vehicle, the radiation pattern of the small dipole antenna should be nearly omnidirectional, as a result of reduced coupling to the vehicle platform. Communications were established over a distance of 34 km between a base station and a mobile unit equipped with the low-profile antenna. The antenna is useful when low visibility is desired. For example, when a long transmission line is available (up to 30 meters in length), the antenna can



Fig. 14. Low-profile, remote-tuned dipole deployed in a tree.

be separated from the radio set (e. g. , suspended in a tree) and operated in the detached mode, thus enhancing camouflage of the operator.

The narrow instantaneous bandwidth of the antenna is a significant advantage with respect to discrimination against adjacent channel interference. However, since the antenna must be retuned when the frequency is changed, the antenna in its present form does not lend itself to fast frequency hopping (FFH), because of the slow response time of its electro-mechanical tuner.

## 5. RECOMMENDATIONS

Presently, the low-profile, remote-tuned dipole antenna is tuned by manual remote control. It is highly desirable that a model with full automatic tuning be developed and evaluated by potential users. Electromechanical devices are incorporated in the experimental antenna, but full electronic tuning would be preferable for field use, and should be investigated. The efficiency could be increased somewhat by adding loading inductors to the antenna to obtain a more uniform current distribution. The diameter and weight of the antenna should be reduced to facilitate camouflage and deployment. Other techniques for measuring the efficiency of the antenna should be explored to obtain better agreement with theoretical predictions.

A low-profile antenna incorporating the improvements recommended would find many applications in the field, where portability, versatility, and camouflage are of paramount importance. The low-profile dipole antenna can be developed only if the user community establishes the need for it and provides the support.

## 6. ACKNOWLEDGMENTS

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## APPENDIX

### EXPLANATION OF THE LOW EFFICIENCY ACHIEVED WITH EXPERIMENTAL ANTENNA NO. 1

The first model of the low-profile dipole antenna was tuned by means of the parallel tuning circuit shown in Fig. A-1. This tuning circuit was capable of resonating the antenna over a broad frequency range. However, the electrical efficiency was not as good as that obtained with the series tuning circuit.

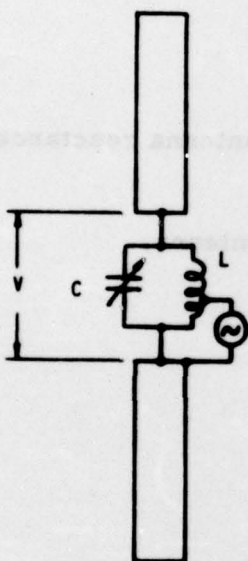


Fig. A-1. Low-profile dipole with tuning network connected in parallel with feed point.

The equivalent circuit of the low-profile dipole antenna using a tuning circuit connected in parallel with the feed point is given in Fig. A-2.

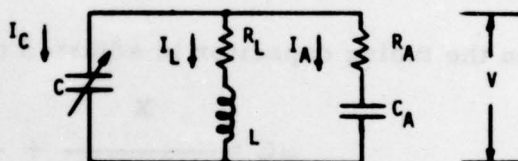


Fig. A-2. Equivalent circuit.

The antenna current,  $I_A$ , is

$$I_A \approx \frac{V}{jX_A}$$

and the current in the inductor,  $I_L$  is:

$$I_L \approx \frac{V}{jX}$$

where  $X_A$  is the reactance of the antenna and  $X$  is the reactance of the inductor. It is assumed that the resistive component of the inductor is much smaller than the reactive component,  $R_L \ll |X|$ , and that the radiation resistance is much smaller than the antenna reactance,  $R_A \ll |X_A|$ .

It follows from these assumptions that the radiated power is

$$P_{\text{Rad}} = \left( \frac{V}{X_A} \right)^2 R_A$$

and that the power loss in the inductor is

$$P_{\text{Loss}} = \left(\frac{V}{X}\right)^2 R_L.$$

The efficiency, which is the ratio of the radiated power to the total power, is given by

$$\eta = \frac{R_A}{R_A + \left(\frac{X_A}{X}\right)^2 R_L}$$

and it is seen to be strongly dependent on the ratio of the antenna reactance to the inductor reactance.

When the tuning capacitor is adjusted to resonate the antenna,

$$\omega C = \frac{X}{R_L^2 + X^2} + \frac{X_A}{R_A^2 + X_A^2}$$

$$\approx \frac{1}{X} + \frac{1}{X_A}.$$

In the above formula, C denotes the capacitance of the tuning capacitor. The inductive reactance required to establish resonance is therefore

$$X \approx \frac{1}{\omega C - \frac{1}{X_A}}.$$

Solution of this equation for the ratio  $X_A/X$  yields

$$\frac{X_A}{X} = X_A \omega C - 1 \approx \left(\frac{C}{C_A} + 1\right),$$

where the antenna reactance is replaced by the reactance of the "antenna capacitance,"  $C_A$ . The efficiency is therefore

$$\eta \approx \frac{R_A}{R_A + \left(\frac{C}{C_A} + 1\right)^2 R_L} .$$

Highest efficiency obtains when the capacitance,  $C$ , of the tuning capacitor is small compared to the "antenna capacitance,"  $C_A$ .

The tuning capacitance, however, cannot be made arbitrarily small because the resulting tuning range would then be too narrow. Thus, in the case of the parallel-tuned low-profile dipole antenna, a wide tuning range and high efficiency are seen to be conflicting requirements.