More efficient operation of the AN/GRC-106

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by David M. Fiedler

High Frequency (HF) radio (2-30 MHz) and its associated HF radio teletype (RATT) systems play a vital role in fulfilling the Army's tactical (division and corps levels) beyond line-of-sight (BLOS) communications requirements. The mainstay of our HF radio equipment is the AN/GRC-106 radio set and various RATT sets (AN/GRC-142, etc.) which use the AN/GRC-106 as the transmission means for the teletype signals. The AN/GRC-106 is a Single Sideband (SSB) Suppressed-Carrier radio with a nominal output power of 400 watts. Designed in the late 1950s, it was originally intended as a division-level radio set. It replaced several WW II and Korean War vintage Amplitude Modulated (AM) radios and the AN/GRC-26D RATT set. Due to its intended use as a division level radio, the AN/GRC-106 design was driven with the following consideration in mind: weight, size (volume), division area coverage (groundwave), RATT configurations small enough to fit in S-250 shelter or JEEP, mobile antenna not to exceed 15 feet (4.6 m), doublet antenna provided to extend radio range and ease of operation. Using this design criteria, it is important to note the following:

The division area of the 1950s and 1960s was considerably smaller than the division area of today, and therefore division-area coverage could be obtained with less effective radiated power.

Ease of operation requirements changed previous complex metering designs to simple red/green or go/no-go circuits, and this somewhat degraded the metering accuracy.

Weight and volume limitations forced the antenna matching network to be located within the Power Amplifier (PA) unit (AM-3349). This limited the size of the antenna matching network to the physical space available within the PA unit. The space available within the AM-3369 was not sufficient to provide the proper components to match the PA to the 15-foot whip antenna which was required for mobile operation. However, enough power was radiated (groundwave) from such a whip to cover the division area of that time.

Electronic Warfare (EW) considerations were not part of the system design.

With all this in mind, let us now examine one of the most common complaints about the AN/GRC-106 radio, namely, lack of range when operating with the 15-foot whip antenna.

In the fall of 1983, the U.S. Army Communications Systems Agency (USACSA), in cooperation with the U.S. Army Electronic Warfare Laboratory and the New Jersey Army National Guard (NJARNG), set up a test HF radio circuit between Greenlawn, Long Island (Hazeltine Corp.) and Atlantic City, New Jersey (National Guard Armory) to test a HF Steerable Null Antenna Processor (SNAP) designed by Hazeltine for protecting HF radio systems from man-made and natural interference. The test path was approximately 100 miles (primarily over sea water) and various antennas were used (wire dipole, 15-foot whip, sloping V and so on). The frequencies were selected by using standard groundwave prediction methods, and frequency authorization was provided by the NJARNG. The predicted most desirable frequencies ranged between 2-8 MHz.

In order to begin SNAP testing, it was first necessary to establish a good solid communications link; this was accomplished using both the horizontal dipole and the sloping V antenna. However, a JEEP (M-151A2)-mounted whip antenna failed to establish an acceptable link. This was of particular concern since the whip was the preferred antenna for the test because of its mobility and ease of installation. Both National Guard and DARCOM field troops present for the tests (including me) were not surprised at this result since all of our field experiences (including Vietnam and Cambodia) indicated that this range performance was typical for the AN/GRC-106. Theoretical propagation predictions indicated that we should be able to communicate easily, and we began to search for the reasons that practice differed from theory.

After checking all antenna components to assure that no physical damage was degrading the system, an "in line" Voltage Standing Wave Ratio (VSWR) meter was inserted between

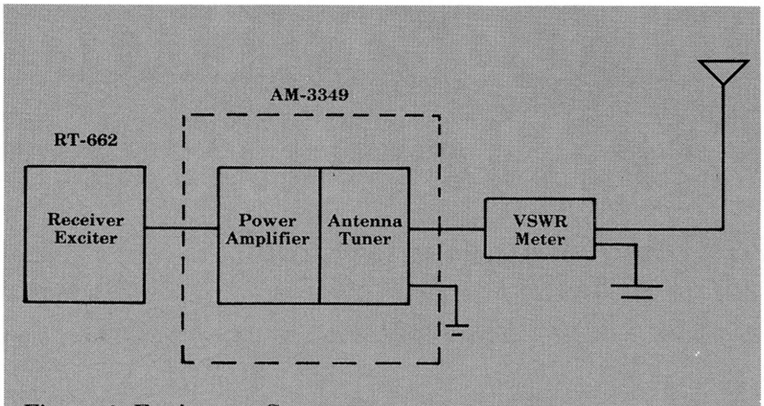

Figure 1. Equipment Setup

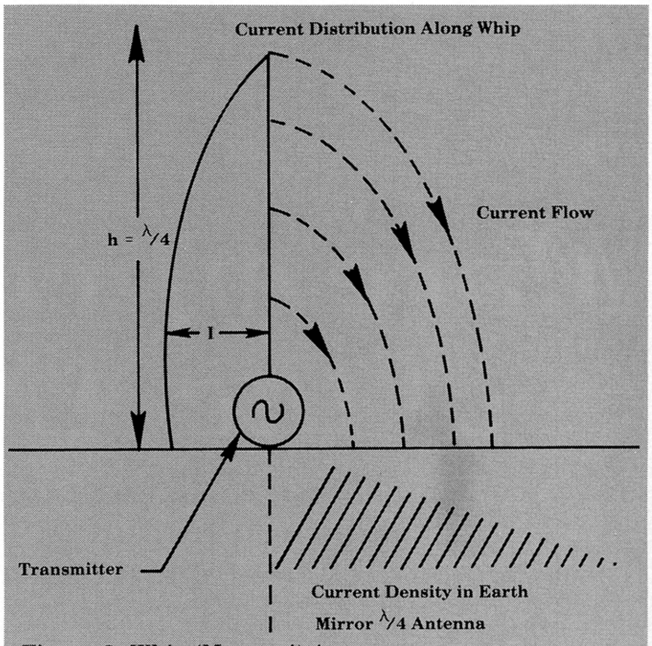

Figure 2. Whip (Marconi) Antenna

the whip antenna and output port of the AM-3349 (see Figure 1). It was necessary to fabricate an adapter cable to accomplish this since the output port on the AM-3349 is for a single conductor and ground while the meter used a "BNC" co-axial connector. After the meter was installed, the AN/GRC-106 was operated in accordance with (IAW) its operating manual, the results were surprising:

When tuning the AM-3349 IAW its published TM so that the PLATE LOAD and ANT TUNE meters centered (green), the maximum output power was not achieved. When the meters were disregarded and the "in line" VSWR meter used instead, maximum forward power increased by about 10%. This was confirmed by measuring the antenna field strength with an ME-61E field strength meter, indicating that the increase in power was in fact being radiated. Ironically, this meter was supplied with the older HF radios but is not supplied with the AN/GRC-106 equipment.

The Voltage Standing Wave Ratio (VSWR), when feeding the 15-foot whip below 5 MHz, was so high that 80% or more of the transmitter output power was being reflected back to the transmitter by the 15-foot whip. In short, the 400 watt-rated transmitter was putting out about 360 watts (due to inaccurate metering) and more than 80% of that was not being radiated by the antenna. As a result, the effective radiated power registered less than 72 watts (less than 1/4 of the expected output). Why? The answer to the first question is relatively easy: the ANT TUNE and PLATE LOAD metering circuits are a compromise between accuracy and ease of operation. Since both meters are of the center-deflection red/green type, the operator does not have to bother fine tuning for a peak reading. However, peak efficiency is lost with this method. This was confirmed by measuring the radiated field strength of the antenna with an ME-61E field strength meter. As the ANT TUNE and PLATE LOAD controls were adjusted on the AM-3349 (after tuning AW the normal procedure) both the "in line" VSWR meter and the ME-61E field strength meter showed about a 10% increase in effective radiated power (when adjusting the controls to the optimum off-center meter readings).

The answer to the second part of the question (high VSWR) is a little more complicated. It is important to understand that for an antenna to radiate the maximum possible signal from a transmitter its input impedance must be the complex conjugate of the transmitter's output impedance. This is commonly accomplished by using a resistive transmitter output impedance that matches the characteristic impedance of the antenna and its transmission line (if any). This resistive impedance occurs when the length of the antenna is a multiple of ½ the wavelength of the operating frequency. For whip antennae (which are actually ½ wavelength vertical dipoles) the ½ wavelength consists of ¼ wavelength of physical conductor (whip) and ¼ wavelength ground reflection, acting as the other part of the dipole (see Figure 2).

With this simple explanation in mind, the physical length required for the ¼ wavelength physical whip can be calculated using the following formula:

$$\lambda = \frac{300}{f\,(\text{MHz})}$$

where λ = wavelength in meters and f is the operating frequency in MHz. To calculate the physical length of an antenna required to operate on a frequency of 5 MHz (which was typical for our system test), we can use this equation to find the required length of the antenna:

$$\lambda = \frac{300}{5} = 60 \text{ meters}$$

and

$$L = \lambda/4 = 15 \text{ meters} = 48 \text{ feet}$$

Since the antenna provided with the AN/GRC-106 is only 15 feet, it is physically too short to radiate efficiently.

In order to cause this antenna to radiate properly, inductance must be added to the antenna in order to cancel the high capacitive reactance and thus make the antenna resonate at the operating frequency. In other words, we must electrically compensate for the physical shortness of the whip. Typically, as in other radio systems, (the AN/GRC-193, for example) this is accomplished by use of antenna matching units which are adjustable inductors and capacitors tuned electrically to match a physically fixed antenna to a given operating frequency (see Figure 3).

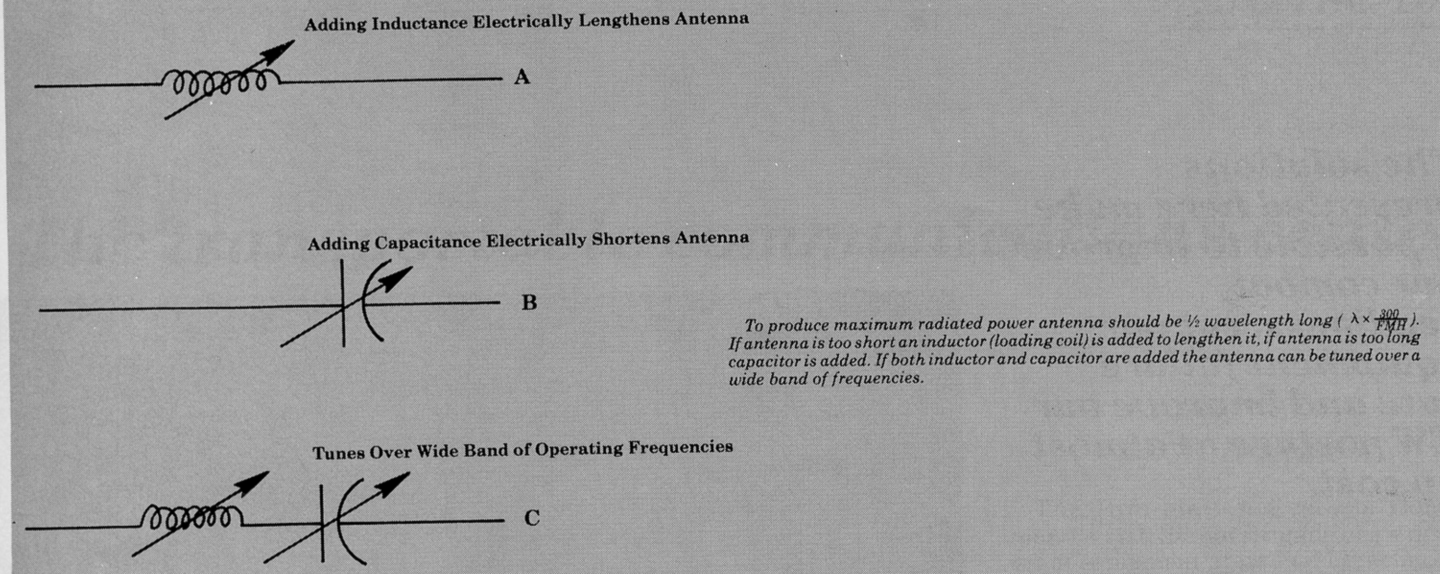

Figure 3. Antenna Tuning Concept

Unfortunately, the space and weight restrictions of the AN/GRC-106 design did not permit a large enough inductance to be placed in the AM-3349; therefore, the 15-foot whip antenna does not match well below 12 MHz. Using the "in line" VSWR meter and the ME-61E field strength meter, we were able to see that the 15-foot antenna did radiate well and have an acceptable VSWR at about 15 MHz; but, below 12 MHz, the VSWR degraded quickly to unacceptable levels and in the 2-8 MHz band predicted to have the best signal propagation characteristics. Up to 80% and more of the transmitter power was not radiated!

The effect

The effects of this mismatch of the antenna to the transmitter can be seen in operational terms in the following areas:

Groundwave range - The power received is directly proportioned to the power transmitted; and, for a typical groundwave path, they are related by the equation:

$$P_R = \frac{P_T x G_T x G_R}{(4\pi \cdot \frac{d}{\lambda})^2} \bullet \frac{C}{d^2}$$

where P = Power at the receiver, C = Constant, P_T = Transmitted Power, G_T = Transmitter Antenna Gain, G_R = Receiver Antenna Gain, λ is the wavelength in meters and d = distance in kilometers. In a practical point-to-point system, all gains are fixed. The minimum acceptable received power, P_R is determined by the background noise and interference including any jammer power in the received band width. The maximum range, d_{MAX}, at which the received signal power drops to $P_{R\ MIN}$ can be computed from the above operation when C is known. For our purposes, it suffices to note that the effect of reducing P_T by mismatching the antenna to the transmitter operating frequency will cause a corresponding range reduction.

This explains why actual groundwave range seen in the field when using the AN/GRC-106 operating below 12 MHz, rarely meets either the published equipment planning range (80 Km) or the groundwave range predicted by the radio propagation charts. These ranges are calculated assuming that the transmitter will radiate efficiently into a matched antenna.

Equipment failure - Power not radiated by a mismatched antenna does not just disappear. The high VSWR indicates that this power is reflected back to the transmitter via the transmission line. This reflected power is then dissipated in the power amplifier causing components to carry more current and heat than they were designed for. This then causes an excessive failure rate of PA components.

Electronic warfare considerations - In order to have an acceptable grade of service (GOS) in an HF radio system, the desired signal should be a minimum of 10-15 dB above any noise or undesired signal level. When the desired signal is being "jammed", it simply means that the undesired signal (jammer) has reduced this margin below what is necessary for reception. Since power at the receiver is directly related to transmitted power (see above), we have degraded our effective transmitted power in the AN/GRC-106 system by mismatching the antenna at the operating frequency. The result is that we have given the jammer a greater chance to be the more powerful signal at the receiver. In this case a 400 watt (48dBW) transmitter capability has been degraded to 72 watts (41dBW). In other words, a jammer can now transmit a 7 dB less power to achieve the same jamming effect upon our communications systems.

In short, the effect of the antenna matching design in the AN/GRC-106 has reduced the range, below 12 MHz reduced system quality, increased failure rate and increased our vulnerability to man-made noise and enemy electronic (EW) countermeasures (ECM).

Our allies' solution

The Federal Republic of Germany is also a user of the AN/GRC-106 radio, but they have been quicker to recognize its problems and act to solve them than we have. The German solution has been to add on an additional antenna matching unit to the radio. This matching unit automatically senses the operating frequency of the radio and tunes its own matching network, independently of the matching network in the AM-3449, until an acceptable VSWR is achieved. This unit is produced in the United States by the RF

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COMM division of the Harris Radio Corporation. While physically quite large, it does provide an acceptable VSWR across the operating band of frequencies, greatly improving efficiency and extending communications range on frequencies below about 12 MHz.

My field expedient solution

The solution to the metering problem is really rather simple. After tuning the radio set using the normal procedures, repeat the last step in the tuning procedure using either an "in line" VSWR meter (note that an adapter cable will have to be fabricated since the AN/GRC-106 uses a single conductor line between the PA and whip antenna) or a field strength meter. Adjust the PLATE LOAD and ANT TUNE controls until the VSWR meter and/or the field strength meter read maximum (peak) radiated power. Then check the VSWR to assure that the reflected power is at a minimum. Continue adjusting controls until maximum forward (radiated) power and minimum reflected power is attained. Disregard the meters in the AM-3449 for this last step only.

The antenna matching problem also has a simple solution. Since the antenna is physically too short and the antenna matching circuitry does not have enough inductance to electrically lengthen it sufficiently for efficient operation at the frequencies of interest (2-12 MHz), it must then be physically lengthened until its physical length is sufficient to place its impedance within the range of the existing matching network. This can be done by adding three standard whip sections (MS-116A) to the antenna supplied. This will make the antenna approximately 24 feet long, and the resulting structure will provide an acceptable VSWR down to about 2 MHz using the matching procedures described above. There are drawbacks to doing this:

a. The longer (24-ft) antenna is more likely to be damaged by obstructions, and mobile operations may be hindered due to increased length. Also camouflage is made more difficult.

b. The mounting base (AB-652/GR) supplied to mount the antenna and keep it vertical was not designed to support the extra length. If left unsupported, the antenna will bend over on its base. Antenna support, however, is not too severe a problem, and it can be accomplished by rigging any ridged non-conductor such as a dry wood pole or length of plastic pipe along the bottom sections of the antenna to stiffen the mount base. Pole or pipe lengths of about 12 ft are sufficient to accomplish this. Non-conducting plastic "cable ties" or twine could be used to securely tie the antenna sections to the pipe or pole.

These techniques make it possible to improve our combat readiness, cut our equipment failure rate and improve our EW posture at almost no cost. Unfortunately, this is but another example of: "the word" just not getting down to the operational troops, and the operational troops not knowing their equipment well enough to question its performance.

In my research for this article, I was unable to find any TM, FM or POI except for the German documents, that identified either a mismatch problem in the AN/GRC-106 or a field fix. This information should be included in both our training courses and our literature so that our troops can be aware of equipment characteristics and problems to get the most out of their equipment.

Obviously, when this happens we will be a more professional, more efficient and combat ready signal force better able to do our part in winning the air-land battle.

Mr. Fiedler was commissioned in the Signal Corps upon graduation from the Pennsylvania Military College in 1968. He is a graduate of the Signal Officers Basic Course, the Radio and Microwave Systems Engineering Course, the Signal Officers Advanced Course and the Command and General Staff College. He has served in Regular Army and National Guard Signal, Infantry, and Armor units in CONUS and Vietnam. He has served as Operations Officer of "B" Co. 44th Sig BN Communications Electronics Staff Officer, 1 BN 113 INF (Mech) and Assistant C-3 50th AD. He holds degrees in Physics and Engineering and an advanced degree in Industrial Management. He is presently employed as an engineer by the Project Manager, Mobile Subscriber Equipment (MSE), Fort Monmouth, NJ. He is also the Assistant Division C-E Officer of the 50th AD (NJNG).