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HF TRANSCEIVERS & ANTENNA SYSTEMS

HISTORY OF HF FREQUENCY HOPPING

HF HELP FILES

Q-MAC Electronics Pty Ltd

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1 From the Vietnam War to contemporary applications

1.1 History of Frequency Hopping

The need for secure radio communications dates back to the Second World War. During the War, both sides routinely utilized COMINT (Communications Intelligence), which primarily involved the interception of radio traffic. The ability of the British and American Forces to routinely intercept high frequency (HF) radio traffic meant they were able to 'crack' Germany's ENIGMA Radio Code, thus giving them a tremendous tactical advantage. Despite this fact, it was not until 30 years later that effective security measures were instigated.

It was the Vietnam War that drove the development of radios incorporating ECCM (Electronic Counter Counter Measures). The Vietcong (VC) were expert at using radio traffic deception. They were known to record US radio traffic requesting air support in bombarding VC positions, then later (once the area was occupied by US forces) the messages would be retransmitted with disastrous consequences. It is against this backdrop that the requirement for a secure combat net radio emerged – ie. one that could not be intercepted or jammed.

In the late 1970s the US put forth a tender document for a system known as SINCGARS (SINgle Channel Ground and Airborne Radio Subsystem). This radio was to provide immunity to eavesdropping and jamming by utilizing frequency hopping. The transmitter and receivers within the network (net) would change frequency many times a second whilst maintaining perfect synchronization automatically. In response, ITT Cincinnati (US), RACAL (UK) and Grinaker (South Africa) all developed VHF combat net radios incorporating frequency hopping. The RACAL and Grinaker frequency hoppers appeared in the market first, as a result of private funding. Unfortunately, the US model lagged behind, given that it was hamstrung by a painfully slow military procurement process.

Frequency hopping on HF was not developed until some time after the first VHF models appeared on the market. Implementing frequency hopping on HF proved to be more difficult, given that HF covers four octaves of frequency as opposed to just one octave at low-band VHF. Furthermore, the propagation medium at HF is much less stable and predictable; the instability of the ionosphere can result in quite dramatic changes in phase delay.

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2 Product Concept

Conventional fixed frequency radios are designed to transmit and receive on a single channel. This fact makes them vulnerable to interception and jamming. Interception is the unauthorized monitoring of radio traffic, whereas jamming is the deliberate disruption of communication, by operating a transmitter (jammer) on the same frequency as the radio traffic. Whilst scramblers and speech encryption devices may provide some degree of resistance to the threat of interception, they are ineffective against jammers. Frequency hopping is the only effective counter measure to both forms of electronic attack.

A frequency hopping radio is capable of hopping its operating frequency over a given bandwidth many times a second (with HF radio, this bandwidth is limited due to changes in propagation). Synchronization data is periodically transmitted and decoded to ensure that the transmitter and receiver keep hopping in synchronism with each other, thereby maintaining intelligible communication even when under severe electronic attack.

The hopping sequence follows a pseudo random pattern, which usually has an extremely long repeat time. This renders the hopping network virtually impossible to intercept or jam. Only the network users who have programmed their radios with the same frequency, sideband, and hopping code can communicate.

In a frequency hopping network, one station is designated as "Master". This station (usually a base station radio) is responsible for transmitting the synchronization data to the "Slave" stations (usually manpack radios). There can be any number of Slaves within a network.

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3 Effectiveness of Frequency Hopping against Jamming

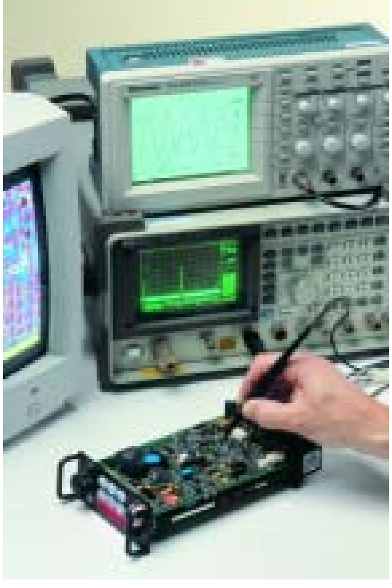
Whilst frequency hopping alone is an extremely effective measure against jamming and other unwanted transmissions, the introduction of two features in particular have further improved the security of HF frequency hopping nets. These are “Smart Hopping” (also known as “Intelligent Hopping”) and the use of single sideband (SSB) for voice transmissions.

3.1 Smart Hopping:

Smart Hopping enables avoidance of blocked channels. The radio net, via the Master, acquires information on the signal strength of each channel within the hop set. All members of the net receive this data automatically and consequently blocked channels are avoided. Continuous updating occurs in order that changing band conditions are accommodated.

3.2 Use of SSB for Voice Transmissions:

In order to mount an electronic attack on a frequency hopping net, an ECM (Electronic Counter Measures) Unit must first identify the presence of the hopping net within a defined frequency range. The ECM Unit must then attempt to determine the geographic location and either crack the hop code or follow and jam the transmissions.



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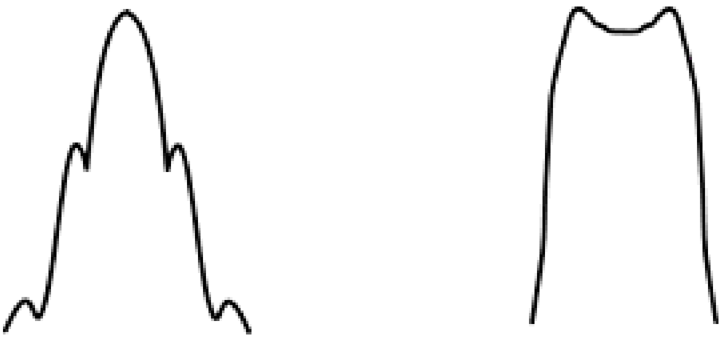
4 HF Spectrum

The HF spectrum is typically very crowded and contains a myriad of signals and noise (refer Fig. 1). Therefore, in identifying a hopping net, the task is made easier if the transmissions have a coherent or characteristic signature. For example, frequency hopping radios that use digitized voice transmissions employ PSK (Phase Shift Keying) or FSK (Frequency Shift Keying). Such transmissions are well defined and readily identifiable (refer Fig. 2).

Figure 1 - Typical HF Spectrum Occupancy



Phase Shift Keying (PSK) & Frequency Shift Keying (FSK)

Figure 2 Instantaneous Spectrum View of HF Digital Voice Hopper.

Certain radios, however, use SSB voice as opposed to digitized voice transmissions. The instantaneous spectrum of an SSB voice transmission is characteristically noise-like (refer Fig. 3). Furthermore, there is no output whatsoever between syllables. This renders such radios extremely difficult to intercept.

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Figure 3 Instantaneous spectrum view of HF SSB voice hopper

These differences become more apparent when observing transmissions over time (using a spectrum analyzer set to Peak Hold or Accumulate). With a digitized hopper, the hop channels are easily identified since the output is nearly constant (refer Fig. 4). In comparison, the hop channels of an SSB hopper are more difficult to identify, since on many channels there is no output due to the voice cadence (refer Fig. 5). Synchronization transmissions, which often employ FSK, may appear as discrete line spectra (also refer Fig. 5).

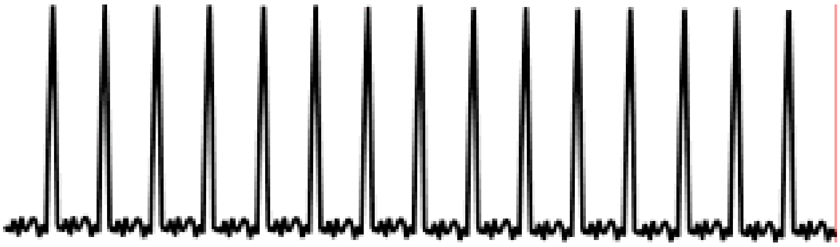

Figure 4 Wideband spectrum of HF digital voice hopper, accumulated over time.

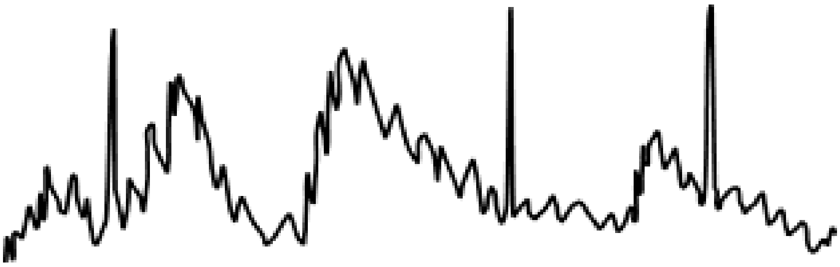

Figure 5 Wideband spectrum of HF SSB voice hopper (inc FSK sync bursts), accumulated over time

An added advantage of using SSB for voice transmissions is power efficiency. With SSB there is no output between speech syllables (whereas alternative digital methods produce output continuously on speech); this results in significantly lower current drain on the manpack battery system.

Other Important Features Relating to HF Frequency Hoppers

Aside from security against interception and jamming, there are a number of other features that should be considered with respect to HF frequency hopping manpacks. These include (but are not restricted to) the following:

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5 Actual Field Performance:

Actual performance in the field is subject to many variables, some of which are controlled by external factors (such as sun-spot activity, ionospheric conditions, terrain and electrical interference). However, the specification of the radio system itself is also critical. Key factors, which will improve the field performance of an HF frequency hopping manpack, include radiated power (affecting the quality of transmission), receiver sensitivity and third order intercept (affecting the quality of reception), and power consumption (affecting operating time). These are described in more detail below:

5.1 Radiated Power:

The power radiated from a manpack antenna system is ultimately the best indication of effective transmission. Radiated power is increased with higher radio power output and an efficient antenna system. The most accurate measure of radiated power is antenna current. Systems that maximize antenna current, as opposed to minimizing VSWR, are optimal.

5.2 Receiver Sensitivity & Third Order Intercept:

The best measures of receiver efficiency are receiver sensitivity and third order intercept. Receiver sensitivity should be as low as possible – ideally <0.5µV (for a 10dB signal to noise ratio). This measures the radio's ability to receive a signal, even when very weak and 'below the noise'. Third order intercept is something that is rarely quoted on product brochures, but is equally important. This measures the radio's ability to discriminate a wanted signal (on frequency) from an unwanted signal (off frequency). A radio with a poor third order intercept is 'broadband' picking up all signals from surrounding frequencies.

5.3 Power Consumption:

Whilst a high radio power output is desirable in terms of the quality of transmission, most high-powered sets are unsuitable for manpack use, given that they consume excessive battery current. It is important to consider both aspects when weighing up field performance. An HF manpack should be able to operate on its battery system for at least 8 hours (assuming a duty cycle of 10% transmit and 90% receive/standby).

5.4 Size & weight:

The size and weight of an HF manpack is also critical, as it will frequently be used whilst on foot, over long distances. Early HF manpack radios weighed more than 10kg (for the radio alone) – without the tuner, antennas, battery, chargers and backpack. Thankfully, manufacturing technology has improved significantly and now the average weight of an HF manpack radio is around 2.5 to 3kg. The smallest HF manpack radio available on the market is the HF-90 from Q-MAC (Australia), weighing just 1kg! *Refer to the Case Study at the end of this article.*

5.5 Ancillaries & Options:

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Another consideration should be the availability of radio ancillaries and options. A good selection of antenna systems (to suit different applications) is paramount. The ruggedness of the battery system and availability of various chargers are also important factors. Most HF manpack radios also offer a variety of other options such as data capability, CW (morse-key) mode, Selcall (Selective Calling) and ALE (Automatic Link Establishment).

5.6 Mechanical Aspects:

The vast majority of HF frequency hopping manpacks meet Military Standard 810E. Whilst this specification ensures mechanical robustness, it does also carry a high price tag. When considering a particular application where HF frequency hoppers are required, 'fitness for purpose' should be the overriding consideration with respect to the mechanical construction. Serviceability is also an important factor. Some manufacturers quote MTTR (Mean Time To Repair), which can be a helpful indicator.

5.7 Price:

Of course, price is also a very important factor when deciding on a suitable HF frequency hopping manpack. This can vary depending on the particular model and the options/accessories required. However, generally speaking, HF frequency hopping manpacks range from around US$15,000 to US$25,000 per system. Some newer models available on the market do sell for as little as US$5,000 to US$10,000, without compromise to performance.

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6 Manufacturers of HF Frequency Hopping Radios

The table below shows a selection of HF hopping manpack radios, which are sold internationally. Key specifications and features are noted for each:

Model	Panther H	TR178B	AN/PRC-138	HF-90	Skyhopper	HF-6000	41G00
Manufacturer	RACAL	Grintek	Harris	Q-MAC	Thomson	Tadiran	Panda
Origin	UK	South Africa	US	Australia	France	Israel	China
Transmit Power	25W	25W	20W	50W	25W	20W	20W
Weight (radio only)	2.6kg	2.9kg	<4.1kg	1kg	2.8kg	3.9kg	2.9kg
Hop Band	64/128/256kHz			256kHz	<6MHz		64/128/256kHz
Hop Rate	5/10/sec.		20/sec.	5/sec.	10/20/sec.		5/10/20/sec.
Voice Transmission	SSB		Digital	SSB	SSB	SSB	SSB
Smart Hopping	Yes	No	Yes	Yes	Yes	Yes	No

A more comprehensive account of different manufacturers' HF frequency hopping radios, can be found in the 2001/2002 edition of "Jane's Military Communications Yearbook". Refer to the Jane's Website for details: http://catalogue.janes.com.

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7 Frequency Hopping in a Modern Context

Many changes have occurred, with respect to HF frequency hoppers, since their introduction shortly after the Vietnam War - the most obvious being the introduction of new design technologies. With the advent of SMD (Surface Mount Device) components, manufacturing processes have become more reliable and the size of radios have reduced significantly. Furthermore, due to the use of integrated circuits and SAW (Surface Acoustic Wave) technology, made available by the computer, satellite and cellular telephony boom, manufacturing costs of newer models have decreased significantly.

However, it is not only the design technologies that have changed over the years. Buyer behaviour, as well as the end-user base, has also evolved.

7.1 Trend Toward Purchase of COTS Equipment:

Most Military/Defense establishments around the world are now starting to question the need for expensive Military Specification equipment and instead considering 'fitness for purpose'. The result is a definite trend toward the purchase of COTS (Commercial Of The Shelf) equipment, particularly for non-combat applications. Most commercial equipment has already undergone the scrutiny and the competitive pressures of the commercial market and is therefore quite suitable for military applications. In many instances, manufacturing quality and mechanical robustness is improved considerably to service dual markets – both civilian and military.

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A number of HF manufacturers have responded to this trend, releasing ruggedized commercial-grade HF manpacks for military use. However, only Q-MAC (Australia) has released such a manpack incorporating military-grade frequency hopping. *Refer to the Case Study at the end of this article.*

7.2 New Applications for HF Frequency Hoppers:

Unfortunately, improvements in technology have also benefited hostile militants and insurgents. The major Japanese HF radio manufacturers (eg. Kenwood, Icom and Yaesu) offer low cost amateur HF units that can be modified in a trivially simple fashion to obtain full HF frequency coverage. Using these units, militants can monitor and jam strategic HF communications, as evidenced during the war in Bosnia. This use of EW (Electronic Warfare) has meant that Peace-Keeping Forces around the world have had to equip with HF frequency hopping radios, to ensure secure communications.

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With the reduction of radio manufacturing costs and the release of appropriate COTS systems, many third world and developing countries are also equipping their forces with HF frequency hopping radios. Such sets had been previously ‘out of reach’ due to the incredibly high costs involved.

The factors mentioned above have also lead to the use of HF frequency hopping radios by a number of larger aid/relief organizations. Many such organizations would otherwise be seriously compromised in their operations, through interception and jamming of radio traffic. This trend is likely to continue, with some of the smaller NGOs (Non Government Organizations) also finding themselves in similar situations.

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8 Q-MAC HF-90 Frequency Hopping Manpack: A Case Study

Q-MAC Electronics (Australia) has released the HF-90 Frequency Hopping Manpack. This product builds on Q-MAC's standard HF-90 radio, which has been available since 1995 and has seen service in many countries throughout Asia/Pacific, Africa and Europe. Rated at 50Watt PEP and weighing only 1kg, it has the best power to weight ratio of any unit in the marketplace.

The HF-90 demonstrates excellent performance in the field, radiating power very efficiently via its TM-90 tuner/antenna system. It has a receiver sensitivity of just 0.25µV and an excellent third order intercept of +18dBm (achieved by way of a GaAsFET mixer). In addition, despite its 50Watt power output, it draws very little current from its battery; only 310mA on receive and typically between 5-7A on transmit.

Operation is extremely simple, and use within hopping mode is no more complex than in fixed mode; the hop mode button is simply pressed to obtain the security of hopping. The hopping algorithm is based on DES (Digital Encryption Standard), which offers excellent security over tactical timescales and in the crowded, noisy multi-net environment of HF.

Hopping nets using the Q-MAC HF-90 Manpack will be effectively undetectable to an enemy monitoring fixed channels, given that the hop rate is greater than or equal to the syllabic rate. Effective jamming of the hopping net is impractical, since the 256kHz bandwidth demands a proportional increase in jamming power of between 10 - 50 Kilowatts.

Even the more technically sophisticated enemy forces, using ESM (Electronic Support Measures) receivers and Fast Following Jammers, are thwarted by the HF-90's use of SSB modulation in hop mode. In order to intercept, jam and track the DES code it is necessary to detect each 'dwell' on a channel and build up a pattern. As SSB speech has a low duty cycle and only produces RF power during syllables, a large percentage of dwells are undetectable. Furthermore, in the crowded noisy HF band, sorting out the wanted signal from unwanted is an insurmountable task. The synchronization bursts are also protected by pseudo random allocation in time and frequency.

Q-MAC has supplied the HF-90 Frequency Hopping Manpack to many military organisations, as well as peacekeeping forces and aid/relief agencies. With prices starting at around US$5,000, it is the most competitively priced HF frequency hopper available worldwide.

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9 Other Information

9.1 Author

Mr Rod Macduff BSc, BA, MIEEE, MIEE, FIEAust

Rod Macduff is Managing Director of Q-MAC Electronics which is a specialist supplier of HF Communications to the Humanitarian, Aid & Relief and Military organisations. Rod Macduff worked with Racal BCC for 10 years on the Jaguar V tactical hopping radio and travelled extensively consulting with armies on their secure communication issues. The Q-MAC HF-90 hopping radio is in service in 75 nations and has been adopted by Humanitarian, Aid & Relief, Army, Police and Intelligence organisations.

9.2 About Q-MAC Electronics

Q-MAC Electronics is specialist designer and manufacturer of HF Transceivers. The flagship product the HF-90 is the world's smallest high performance HF SSB Transceiver. The HF-90 and Q-MAC Electronics have been awarded many accolades and is currently used by thousands of users in over 80 countries worldwide. The HF-90 is one of the most versatile HF transceivers available and is suited to military, paramilitary and humanitarian aid and relief applications.

Q-MAC offers the HF-90 in a variety of configurations suited to manpack, vehicle and base station applications. A full complement of accessories is also offered for use with the HF-90; including antennas, field battery charging accessories, carry packs/cases and more. All Q-MAC products are backed by the company's strong commitment to after sales service, support and certified ISO9001 quality standards.

9.3 Contact Details

For Further Information Contact;

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