**A MULTIMEDIA RF EXTENSION
FOR
LAW ENFORCEMENT, MEDICAL, UTILITY, EDUCATIONAL, MILITARY USES**

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ABSTRACT

Interested in wireless/ fiberless RF communications? How about up to 155 MBS!! This paper covers the use of commercial off-the-shelf (COTS)/ non-developmental item (NDI) equipments for military and civilian situations. For this case, we are talking about a terrestrial line-of-sight (LOS) microwave system operating in the 7-8 GHz band at standardized⁶ data rates: DS-1/E-1 (1.544/2.048 MBS); DS-3 (44.736 MBS); and STM-1/OC-3c (140/155.52 MBS)*. This is a transportable

communications system for data, voice, fax, image, and full-motion video. The DS-1/DS-3 capabilities were demonstrated at Global Yankee 95, an Air National Guard exercise in Jun 95 (GY95). The STM-1/OC-3c capability will be demonstrated at GY 96 in Aug. 96 (GY 96).

INTRODUCTION

This is an in-house effort within the Command, Control, Communications Directorate (C3) of Rome Laboratory (RL) to demonstrate the use of high data rate, comm equipment to provide electrical or optical connectivity for multimedia

***Electrical :**

synchronous transport signal or STS (ANSI T1.105)
Synchronous Digital Hierarchy or SDH (ITU-T Recommendation)

Optical :

optical carrier or OC Stds used

The rates⁶ (MBS) are as follows:

			BIT	PAY
OPTIC	ELECT	SDH	RATE	LOAD
OC-1	STS-1	--	51.84	51.11
OC-3	STS-3	--	155.5	150.3
OC-3c	--	STM-1	155.5	

applications. This effort is called the Multimedia Wireless Extension (MWE) and a summary is presented here:

OBJECTIVES: COTS/NDI EQUIPMENTS
TACTICAL OC-3c LOS COMM
INTEROPERABILITY/COMPATIBILITY
MILITARY/CIVILIAN DUAL-USES
JOINT AF/ARMY/NAVY PROGRAM

TECHNICAL ISSUES: LOS BETWEEN TERMINALS
FREQ. AUTHORIZATION
EQUIPMENT INTERFACES
DISTANCE BETWEEN TERMINALS
EQUIPMENT COSTS

PAYOFF: REMOTE CONNECTIVITY
NEW DEPLOYMENT/RESTORAL APPLICATION
BASELINE FOR HIGHER RATES - OC-12
CANDIDATE FOR NYSTEC
MANY MILITARY/CIVILIAN USES

The capability includes simultaneous transmission/reception of multimedia data/voice/fax/image/full motion video. Some examples of military uses are to provide: telemedicine information such as patient conditions/records/scans and video consulting conferences for a Medivac unit; command and control information for an Air Operations Center (AOC); or surveillance radar data for a remote airstrip control tower. Some of the capabilities provided for civilian (commercial) uses are: consulting/diagnosis at a distance for EMT/medical personnel in remote or disaster areas; real-time situation updates for law enforcement personnel involved in locating lost people or wanted felons (search and rescue); and communications for utilities during times of massive power outages due to natural causes or terrorist activities. Also, while not as obvious, distance learning⁴ can use this capability in rural, underserved locations to share teachers/professors for

more than one group of students. The equipment we are using to do all of this is the transportable LOS microwave TCM-904B transceiver purchased from Loral Conic / Terracom (L/C/T) and either a digital or optical MODEM/MULDEM.

TRANSPORTABLE MICROWAVE RADIO IN A DIGITAL WORLD

History

Transportable microwave radio has been around for over 25 years and has had a small, but important, roll in supplying telecommunication service for specialized applications. This class of microwave radio has been used to supply temporary point-to-point service for analog video and frequency division multiplex (FDM), and in more recent years for low capacity digital service.

Early transportable microwave relied heavily upon the phased locked cavity oscillators developed in the early seventies. These oscillators could be linearly modulated with a baseband signal and could be readily tuned by providing a reference synthesizer, or a switched reference crystal. By providing a variable frequency reference, the radio designer could provide a small, tunable, modulated transmitter operating in the 1.5 to 2.2 GHz frequency band. Frequency multipliers were added to extend the operating frequency of this type of radio into all of the common telecommunications bands.

Almost all of these radios were frequency modulated (FM) and were considered as a "re-mod" (non-heterodyne) radio. They were used to provide temporary service for point-to-point common carriers requiring emergency restoral, Electronics News Gathering (ENG), radar remoting, government range video feeds, and other special transmission applications. As digital radio became a reality, baseband circuits were modified to accept simple formats, i.e., 3 level partial response, 4 level pulse amplitude modulation (PAM), 4 or 8 phase shift keyed (PSK), etc. These modulation formats made modest demands on the transmitter and were capable of providing service for data rates up to 45 MBS (DS-3). Most formats had bit efficiencies from 1 to 1.5 bits/sec/Hz (b/s/Hz), plus they occupied a relatively wide bandwidth (BW).

Present

The requirement for more efficient use of bandwidth has demanded complex formats with higher bit efficiencies. Today, 16 quadrature amplitude modulation (QAM), 64 QAM and 128 trellis coded modulation (TCM) formats are very common. The demands for better radio design have increased with the increase in modulation complexity. No longer were simple radio schemes able to provide adequate service for transportable microwave to carry high data rate, digital traffic. Amplitude and phase linearity requirements could not be met with the older component technology. A new radio with very good intermodulation

distortion and phase linearity would be required to maintain a good quality of service (QOS) for the new world of digital radio. New radio systems would need to be developed to handle data rates greater than 45 MBS (DS-3). The general trend in communications growth over the past 10 years has been to place more information, voice and data, into an already crowded spectrum. Today, it is common to see 155.52 MBS of data crammed into 30 MHz of RF BW.

New Design Approach

MULTIMEDIA WIRELESS EXTENSION (MWE)

Figure I

The design of any high capacity, transportable radio must be flexible enough for many differing requirements. The approach shown in Fig I allows a variety of user equipments and antenna systems to be selected when designing an LOS link. The TCM-904B does this. As you can see, the system consists of a series of independent blocks. The user equipment takes on many forms depending upon the service to be provided. The radio portion is designed to interface with MODEM/MULDEM formats ranging from simple FM to the more complex 128 TCM format.

TCM-900 SERIES RADIO²

The TCM-904B is part of the TCM-900 series of L/C/T radios (transceivers). It is a dual conversion, heterodyne transceiver that provides transmit/receive signal processing, duplexing for antenna connection, and transmitter power amplification (PA). The transceiver provides the up/down conversion process and is conditioned, controlled, and monitored by a microprocessor controller that allows conditioning for any digital modulation format. RF tuning is in 1 MHz steps across the operating frequency band.

Its transportability is a result of its light weight and small size. Each unit weighs 76.3 lbs and measures 19"x17.5"x19". A 2 or 4 ft. diameter parabolic antenna is used for this arrangement. Everything is mounted on a simple 3-legged tripod. A telescoping tower can be used when additional antenna height is required to achieve LOS.

Transmit Signal Processing

The data signal entering the IF signal processing circuits is amplified and level controlled (ALC) by a step attenuator. The ALC allows adjustment for different characteristics of interface cables that might be used, thus establishing a fixed power level for the transmit PA. The power level provided to the final PA is critical in a digital system. To maintain the amplitude linearity required by complex digital modulation

formats, and to provide enough headroom for peak to average excursions of the modulation signal, the power amplifier must be operated below its 1 dB compression point. The power level varies with the modulation format used and the characteristics of the power amplifier. For example, the 64 QAM MULDEM* used for GY 95 requires the power level to be reduced, or "backed off" by about 8 dB from the 1 dB compression point. However, for 16 QAM modulation, less "backoff", typically 6 dB, would be required. The amount of "backoff" is progressively decreased as the modulation complexity decreases. For systems operated in the analog mode, no "backoff" is used, and the PA is allowed to operate at saturation (5 to 7 watts or 37 to 38 dBm).

Receive Signal Processing

The critical elements in the receive process are the noise figure and dynamic signal range. The receiver noise figure (NF) is critical in maintaining the best threshold possible and the dynamic range is critical in providing the best "far/near" performance. More dynamic range provides more fade margin. The first receive downconverter provides both of these functions. It contains a low noise amplifier (LNA) to establish the system NF

* MULDEM is a multiplexer/demultiplexer AND a modulator/demodulator in one unit. The one used here is a Northern Telecom³ DM-33 with:
4 DS-1 + 3 DS-3 = 151.317 MBS

and a PIN attenuator to help increase the receiver dynamic range. The LNA allows a 3 db noise figure to be maintained at the RF port of the receiver. The PIN attenuator provides about 30 dB of automatic gain control (AGC) range and the main receive IF processing circuits provide about 55 to 60 db of AGC range. These two combined will give the receiver 85 to 90 db of dynamic range. The down converters use an image rejection mixer to eliminate the image frequency created in the mixing process. The RF signal is mixed with a local oscillator (LO) signal derived in the receive synthesizer to achieve the desired 1110 MHz IF at a BW = 50 MHz between the 3 dB points.

The second downconverter in the receive signal path converts the 1110 MHz signal to an IF of either 70 MHz or 140 MHz depending upon the interface requirements. The downconverter contains 4 individual SAW filters providing IF selectivity for either wideband or narrowband signals. To accommodate some of the older MODEMs with a wider BW, a 40 MHz filter is selected by the microprocessor controller. For the more current MODEM/MULDEM designs, a narrowband filter of about 30 MHz is used.

How Far Will It Go?

This question is often the first question asked when a transportable microwave system is considered. For fixed terrestrial microwave systems, location of the end points for each link are generally known well in advance of installation.

Also, path terrain, climatic conditions, and availability/reliability requirements are defined. The system engineer can then design for antenna size, transmitter power, receive threshold, and diversity considerations.

For transportable microwave links, the path design parameters are usually not known in advance. Figure II illustrates the relationship between path length, receive signal level (RSL) and fade margin (FM) for a 64 QAM, 151.3 MBS, transportable system. Antenna sizes of 2 and 4 feet were used to make these calculations.

Figure II

The free space path loss and antenna gains can be determined from equations (1) and (2):

Free Space Path Loss¹: (1)

$$FS_L = 96.6 + 20\log_{10}F + 20\log_{10}D$$

F = frequency in GHz
D = path distance in miles

* FM = frequency modulation
FM = fade margin

Antenna Gain¹: (2)

$$G = 20\log_{10}D + 20\log_{10}F + 7.5$$

D = antenna diameter in feet
F = frequency in GHz
7.5 = typical efficiency factor

The RSL at the receiver input can be calculated as follows:

$$RSL = P_{TX}(dBm) + G_{TX}(db) + G_{RX}(db) - L_C(db) - FS_L(db) \quad (3)$$

P_{TX} = transmitter power
 G_{TX} = transmit antenna gain
 G_{RX} = receive antenna gain
 L_C = cable losses

When conditioned for 64 QAM transmission, the output power is +29dBm and the receiver threshold is -69dBm. The cable loss is estimated at 2 db each end. Thus, the RSL for a system employing a 2 foot and a 4 foot antenna operating over a 9.5 mile path at 8.0 GHz is calculated :

2' Antenna At Each End: (4)
 $RSL_2 = +29+32+32-4-134 = -45 \text{ dBm}$

4' Antenna At Each End: (5)
 $RSL_4 = +29+37+37-4-134 = -35 \text{ dBm}$

The fade margin (FM) can be found from: (6)

$$FM = |\text{Receiver threshold}| - |RSL|$$

$FM_2 = 69 - 45 = 24 \text{ db}$
 $FM_4 = 69 - 35 = 34 \text{ db}$

At this point the user must decide upon the amount of FM he needs. Referring to Figure II, we see RSL and FM for path distances up to 21 miles. This path distance gives a FM for a 2 foot antenna of only 16 db. This low value of FM may be adequate for some short term

applications; however, moving to a 4 foot antenna system will result in a FM of 28 db, an improvement of 12 db. For a fixed station system, this path would be designed to give fade margins on the order of 40 db.

So, how far will it go? As shown, a transportable microwave link is dependent upon (1) the user's desired requirements (QOS) and (2) the locations where it is to be set up. For some users, a 21 mile link with 4 foot antennas is fine. For others who might require 40 db of FM, this transportable link can only go about 6 miles.

These numbers are altered considerably when other, less demanding, modulation formats are used. For example, if the system were conditioned for 16 QAM use, the transmit power would increase by 3 to 4 db and the receiver threshold would improve by a like amount. This would result in a net improvement of 6 to 8 db in FM for the aforementioned antenna configurations.

ONE EXAMPLE OF HOW THIS IS USED

How about in the telemedicine⁸/teleradiology⁸ area ? This involves the transmission of medical data (consultative text), images (teleradiology), and real-time, full-motion video between medical facilities. This includes files, records, patient conditions, x-rays, and scans of damaged organs. Conferencing with full-motion video between medical specialists is now possible by using a MODEM⁵

operating at OC-3c/STS-3/STM-1 rates. Using a MODEM/MULDEM³ at the DS-3 rate can accommodate this also, but there are missing video frames and images lack good definition.

It is interesting to see the amount of data per modality⁸ and the time it takes to send it for various data rates. This is shown in the following chart :

	MRI 256x256x12	RADIOGRAPH 2Kx2Kx10
Mbits/image ²	1.04	64
images/exam ²	50	4
Mbits/exam	52	256
sec@56KBS	929	4,571
sec@DS-1	33.7	165.8
sec@DS-3	1.16	5.72
sec@OC-3c*	.346	1.7

* assumes all available BW is used for sending an image.

The results of an MRI and a Radiograph can be sent in slightly over 2 sec at OC-3c or in slightly less than 7 sec at DS-3. This "extension" of the expertise of the medical specialist located at a "rear", fixed hospital to remote, field areas often means saving one or many lives.

To completely describe the deployment, set-up, and operation of communications for a telemedicine/teleradiology link would make this paper intolerably long. Ref⁹ will be presented by this author and covers the aforementioned area. It⁹ may be seen at http://www.cny.com/dual_use.

CONCLUSIONS

We have been talking about improvements for full duplex transportable microwave LOS communications that will allow high data rates over links that are relatively easy to set-up and will provide an acceptable QOS^{*} for a reasonable amount of time. The author conducted a survey of COTS/NDI equipment that resulted in selection of the TCM-904B as the most cost effective, easiest to transport, quickest to set-up, with the highest data rate. The MULDEM and MODEM are also COTS/NDI.

Figure III illustrates the uses of this equipment during last year (GY95) and as proposed for this year (GY96).

Figure III

* QOS = quality of service
This is defined by the user as important for the communications system to provide.
Ex: high reliability, high data throughput, low delay, covert operation, etc.

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