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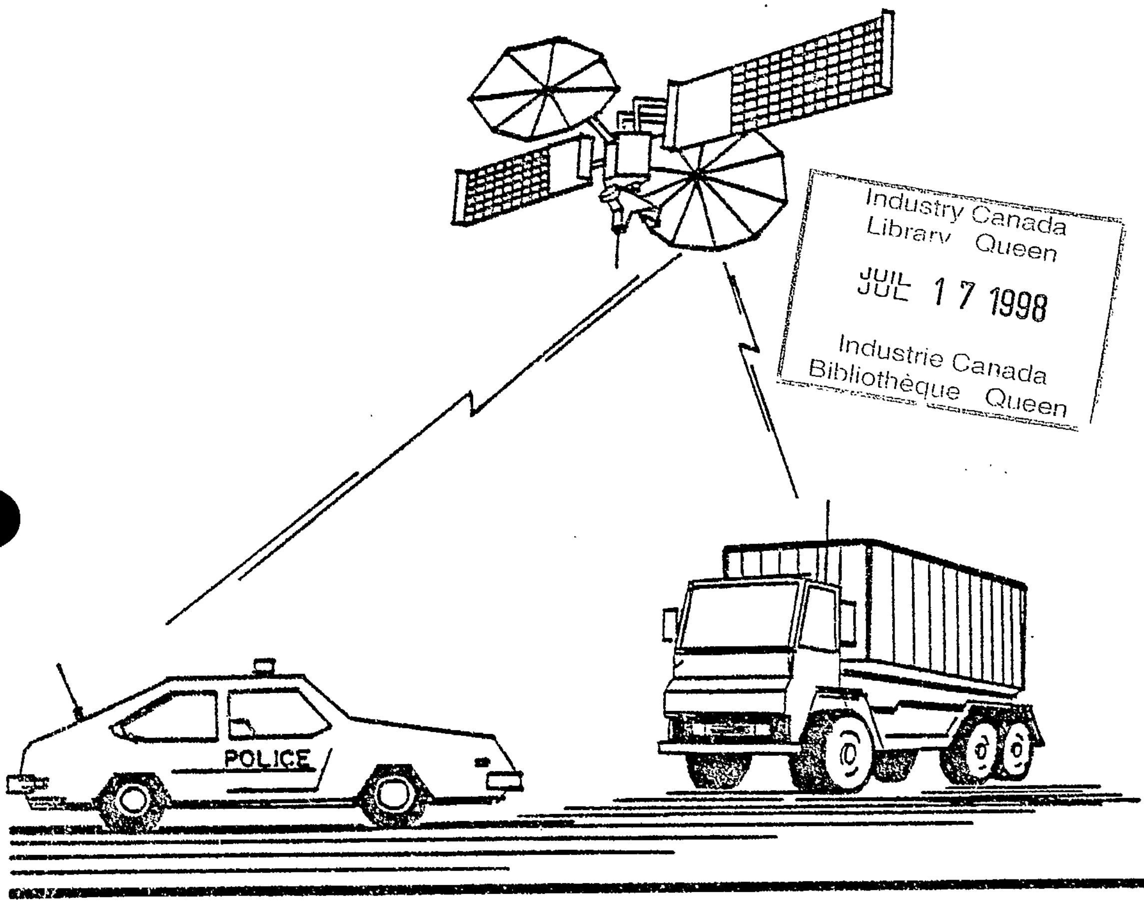
DEPARTMENT OF COMMUNICATIONS



MSAT MOBILE TERMINAL STUDY VOLUME 1

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FINAL REPORT

SURVEY AND TECHNICAL ANALYSIS OF MOBILE RADIO TERMINALS SUITABLE FOR MSAT COMMUNICATION SYSTEMS

final report

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VOLUME 1

RESULTS AND CONCLUSIONS

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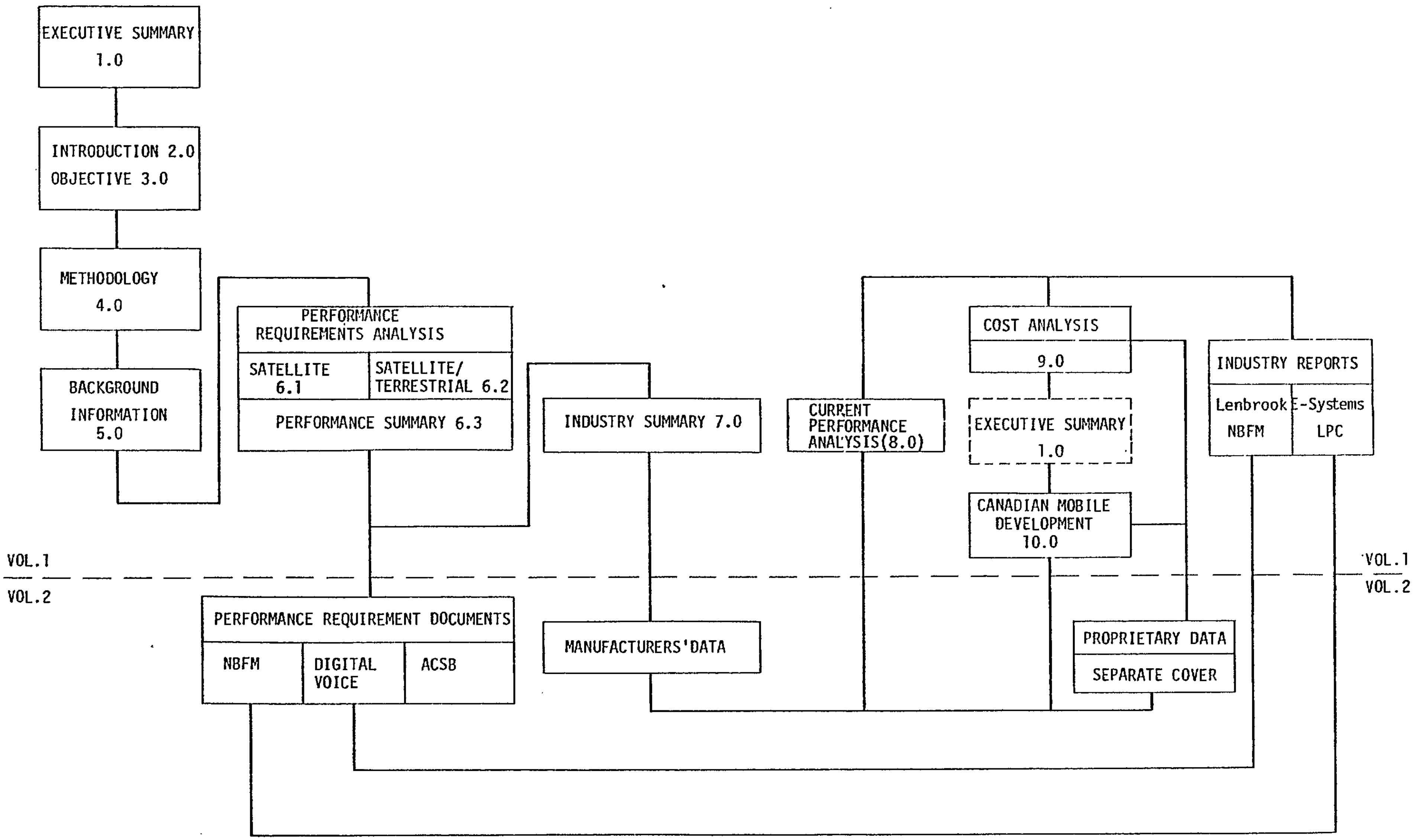


MSAT TERMINAL STUDY

ORGANIZATION OF REPORT

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

The MSAT Mobile Terminal Study examines the requirements, technical difficulties and probable cost of the development and production of mobile terminals suitable for operation within the proposed MSAT communications system.

Related studies indicate that two configurations of mobile terminals are likely to be required to satisfy the projected Canadian market within commercially attractive spacecraft options.

The two configurations, full duplex mobile telephone (MTS) and half duplex mobile radio (MRS), are examined using narrowband frequency modulation (NBFM), amplitude companded sideband (ACSB) and narrowband digital voice (LPC or RELP), considering both a satellite only operation and an integrated satellite/terrestrial operation.

1.2 OPERATIONAL REQUIREMENTS

The analysis of system and operational requirements leads to a complex mobile terminal incorporating demand assigned multiple access (DAMA) through the use of:

- sophisticated signalling protocols
- microprocessor control
- spectrum and power efficient data transmission
- fully synthesized multichannel capability
- mobile identification and selective calling.

These and other features are incorporated into mature terminals designed for operation in the evolving cellular mobile telephone systems such as AMPS. For this reason the AMPS terminal was used as a baseline in the subsequent analysis of performance and cost.

1.3 PERFORMANCE REQUIREMENTS

The performance requirements were considered for both satellite (MSAT) and terrestrial/satellite operation and compared with the performance of state-of-the-art NBFM, ACSB and digital voice terminals. The critical performance parameters were found to be:

- power output of 50 watts, necessary for NBFM and ACSB;

- duplexer bandwidth of 25 MHz, necessary for compatible operation of NBFM in both MSAT and terrestrial components of MTS systems;

- frequency stability, of +/-0.5 ppm, necessary for 5 KHz channel spacing as used in ACSB and digital voice;

- 2.4 kbit data modem used in both ACSB and digital voice;

- 2.2 dB receiver noise figure;

- signalling protocols for half duplex operation in the mobile radio service (MRS).

Although none of the these parameters are beyond the state-of-the-art extensive product engineering will be necessary to incorporate all features in a commercially viable mobile terminal using existing technology.

A significant factor observed during the analysis of the performance requirements is, that in contrast to the terrestrial system environment, the mobile operating in a satellite only system is required to operate over a very small range of signal levels. Thus with the exception of the RF filters, frequency convertors and power amplifiers, almost all of the terminals could be implemented using all digital techniques for signal extraction, signal generation and signal processing.

At this time the only known developments using these techniques are for military purposes.

The eventual fall out of this technology into commercial applications can be confidently predicted. The mobile terminal designed for MRS operation only within the satellite system appears to be an ideal candidate for an early application of this technology.

1.4 SUITABILITY OF EXISTING TERMINALS

No existing or planned mobile terminals were identified as capable of meeting the performance requirements. Electrically the AMPS mobiles available from several sources could be modified for operation in a NBFM mode but not within the constraints of the existing thermal/mechanical packaging.

1.5 INDUSTRIAL CAPABILITY

Throughout the past ten years major international manufacturers of mobile equipment have invested large capital and engineering resources into the development of cellular systems and technology. In view of the imminent decision by the FCC to licence such systems in the U.S.A., major manufactures exhibit little enthusiasm for the development of an MSAT mobile terminal which, it is perceived, will cause a dilution of the cellular market as well as their engineering resources. It is evident however that these companies maintain the technical excellence necessary for the development of an MSAT mobile terminal.

In Canada there is no direct experience in the development or manufacture of 800 MHz mobile radio equipment and with one exception little interest has been expressed in the development of NBFM equipment operating in this band. Strong interest has however been expressed in the development of new technologies such as ACSB, narrowband digital voice or any other viable alternatives that may eventually replace the spectrum hungry FM systems.

1.6 MOBILE TERMINAL COST

Probable cost for satellite and satellite/terrestrial compatible terminals were developed for both the demonstration and operational phases of the proposed MSAT system. Projected cost, although based upon volume production, are quoted for unit quantities. A discount curve has been developed for application to larger quantities.

Additional cost with respect to the available AMPS type mobiles ranges from $850, for a satellite only NBFM terminal, to $6,190 for a narrowband digital voice terminal.

For the operational phase cost projections are based upon VLSI and hybrid technology forecast for use in cellular radios. The projected cost for these units is $2,875 Canadian to which must be added $445 for the NBFM satellite only version; $930 for the narrowband digital voice and up to $1,250 for the ACSB version.

1.7 DEVELOPMENT COST

Development and tooling cost for those elements of MSAT mobile terminals not forming part of existing mobiles terminals was estimated from factory level cost estimates provided by manufacturers. In deriving these costs it was assumed that spin-offs from U.S. military programs would be available at no cost to the MSAT Terminal Program. The estimated development cost for each of the three basic options of NBFM, narrowband digital voice and ACSB are $1,969,000, $1,892,000 and $2,750,000 respectively.

2.0 INTRODUCTION

Through its mandate to develop communication systems to efficiently serve the people of Canada, the Department of Communications has initiated studies to determine the feasibility of providing land mobile communications on a nation wide basis by means of a satellite (MSAT) repeater. As part of these studies ADGA was awarded a contract to investigate the performance requirements and cost of mobile terminals suitable for application in the MSAT system.

This report identifies both the operational and performance requirements for candidate mobile terminals using each of three modulation modes. In order to establish a basis for estimating the cost of MSAT capable terminals these requirements are compared with the performance parameters of existing mobile terminals so as to establish a basis for estimating the cost of MSAT capable terminals.

Finally, the results of an industry survey to determine the potential for development and manufacture of a wholly Canadian MSAT capabile mobile terminal are reported.

3.0 OBJECTIVE

The study objectives, determined by the Department of Communications, may be briefly summarized as follows:

a) Determine capabilities of current and planned terrestrial NBFM terminals operating in the 806 - 890 MHz band.

b) Determine feasibility and cost of modifying commercially available NBFM terminals to meet MSAT requirements.

c) Research and evaluation of the commercial terminal market to identify candidate terminals that meet (or can be modified to meet) the MSAT requirements considering modulation modes other than NBFM.

d) Determine non-recurring and recurring cost, technical problems and any other difficulties which might arise if design, development and mass production of mobile terminals were to be wholly undertaken within Canadian industry.

As a result of preliminary results from other feasibility studies DOC subsequently requested that major emphasis be directed in the area of ACSB and digital modulation terminals rather than the NBFM terminal.

4.0 METHODOLOGY

4.1 INDUSTRY/ADGA CO-PARTICIPATION

The ADGA approach to determining the cost and technical effort required for mass production of MSAT mobile terminals was to develop a set of generalized functional and performance requirements applicable to a broad class of current or planned mobile radio products, but also appropriate for the transformation of such products into satellite compatible terminals. From these, candidate terminals were defined using the generalized functional requirements as the selection criteria after conducting a North American wide survey of manufactured equipment. Next, specific functional, performance and technical requirements for MSAT compatible mobiles were developed for each of the three modulation formats i.e., NBFM, ACSB and NB digital. The documents containing the MSAT terminal requirements are contained in Volume 2 of this report. (MSAT Terminal Requirements.) The next step involved the transmission of these documents to selected manufacturers to allow their engineers to provide a detailed analysis of modifications required with respect to circuits and components in their own current or planned product lines. Manufacturers were asked to identify potential development schedules, technical risks involved and delta costs for terminal production. Table 1 shows the distribution details for the ADGA prepared terminal requirements documents.

Recipient/Requirement Documents	Country	NBFM	ACSB	NB Digital
1. Canadian Marconi Company	Canada	•	•	•
2. E-Systems, Garland Division	U.S.			•
3. Lenbrook Industries Ltd.	Canada	•	•	
4. Motorola Canada Ltd., COM Division	Canada	•		•
5. RACAL (Canada) Ltd.	Canada			•
6. Stephens Engineering Associates Ltd.	U.S.		•	
7. University of Bath, School of Electrical Engineering	U.K.		•	

Table 1. Functional, Performance and Technical Requirements Distribution Matrix.

As part of a pre-planned follow-up procedure, meetings or discussions were held with all of the above manufacturers (with the exception of the University of Bath), after they had received the documents. The results of these meetings are summarized in Section 7 and 8.

The decision to involve industry from the beginning of the study has enhanced the accuracy of the results reported as the manufacturers proved to be in the best position to assess the modifiability of their own products, down to the circuit and component level, in accordance with the ADGA developed requirements.

5.0 BACKGROUND

5.1 CATEGORIES OF SERVICE

Existing land mobile radio services in Canada fall into two major categories, Mobile Radio Services (MRS) and Mobile Telephone Services (MTS).

5.2 MOBILE RADIO SERVICE, GENERAL

The MRS is essentially a dispatch type of operation in which a fleet of mobiles or portables communicate with a central dispatch office (and in some cases with local dispatch offices) and between other mobiles within the fleet using a simplex or half duplex push to talk (PTT) mode of operation.

Large fleets are frequently user owned, or occasionally leased from a supplier. Communications to fleets of mobiles are generally supported by fixed base station(s) or repeater(s) located on high ground within the desired coverage area. Communications take place on a dedicated channel or channels, co-ordinated and licenced by the Department of Communications. The use of multiple channels is generally necessitated by area coverage requirements rather than channel loading and hence the systems are generally classed as single channel per user systems.

For a few metropolitan users only, multiple channels may be required to serve a high traffic density. Typical examples are police and public utilities. Even though at this time many of these systems operate on a basis of manual channel selection they are in effect small trunking systems, in which a pool of frequencies are used to achieve a higher traffic throughout for a given grade of service (blocking probability).

Smaller fleets, particularly in urban areas, are frequently unable to justify the allocation of a single dedicated channel. These users are therefore frequently served through the use of a shared repeater leased from a common carrier (TELCO) or restricted common carrier (RCC). Privacy in these systems is not generally available although the use of tone coded squelch, and in some cases mobile selective calling, does reduce the mutual interference between users of the shared channel.

The level of service in the MRS systems is extremely variable. For the large fleet, grade of service in rural areas is typically good but coverage limitations are generally experienced due to the high cost of establishing and maintaining rural repeater sites. Operation in the VHF frequency band provides maximum coverage but frequently, during summer months, at the expense of co-channel interference from systems with inadequate geographical separation. In urban areas, and for small fleets in all areas, the grade of service is generally poor and frequently subject to interference due to intermodulation and spurious responses. In nearly all cases, and in the absence of co-channel interference, the use of NBFM modulation results in a high voice quality throughout most of the service area.

5.3 MOBILE TELEPHONE SERVICE, GENERAL

MTS usage is generally between mobiles and a fixed subscriber at some point in the Switched Telephone Network (STN). Only a small volume of traffic takes place between mobiles. At present two types of service are offered, MTS in which half duplex mode of operation is used together with operator assisted dialling and call termination and, IMTS which provides full duplex service, automatic channel scanning and direct dialling facilities.

Throughout most service areas which at this time in Canada are restricted to 50 percent of populated areas and only 14 percent of all land areas (Ref. 1, Task 3), the grade of service is very poor and quality is subject to the same variation and limitations as for the MRS. These two factors have contributed to the development of the so called cellular radio systems which are expected to be implemented within major urban areas in North America during the next few years.
The best known of these is the Advanced Mobile Telephone Service (AMPS). The AMPS mobile developed for this service is used as the baseline mobile terminal for this study.

5.4 CELLULAR SYSTEMS, GENERAL

Cellular systems are designed to provide a telephone quality, 26 dB subjective signal to noise ratio, and ten percent blocking grade of service. Functional and operational features are designed to make the MTS indistinguishable from landline telephone service. Thus a called subscriber should be unaware as to whether the call is received from a mobile or from a landline telephone.

This objective has led to the development of a unique modulation format and signalling protocol for the control of routing, hand-off, channel allocation and other system functions. This protocol has been standardized through the Electronics Industries Association (EIA) and is generally referred to using the acronym AMPS (Advanced Mobile Telephone Service). As presently configured, cellular systems are designed for mobile telephone service and they specifically exclude the dispatch service. Although some technical factors are included in the justification for this limited application, it is understood that political and institutional factors were a major influence.

Many of the features found in cellular systems would be required of the MSAT system. These include:

- Demand Assignment Multiple Access (DAMA) of voice channels from a central controller;

- Automatic vehicle indentification code transmitted for purposes of DAMA and call data recording (billing);

- Dedicated paging and access channels;

- Automatic registration in a foreign cell or beam;

- Home cell (or beam) designation;

- Regulated scanning of paging channels;

- Automatic call termination in the event of signal loss.

Other features such as automatic control of mobile power for purposes of limiting co-channel interference, phase ranging and signal strength monitoring are also included in the AMPS cellular system but are not necessarily required for the MSAT system.

5.5 MSAT OBJECTIVES

In view of the expected widespread adoption of cellular systems, and in particular the proposed EIA standard for AMPS compatible mobile terminals, an initial objective of the MSAT system was capability for inter-operation with AMPS compatible mobile terminals. Through this the MSAT service would provide an immediate nationwide expansion of the cellular mobile telephone service to include remote and rural areas as well as the dense urban areas served by terrestrial based installations.

Unfortunately, initial studies indicate that power and spectrum requirements for this capability would place a substantial cost burden on this service.

Subsequently market studies (Ref.2) have indicated, that in Canada the major requirement is for mobile radio (85 percent) rather than mobile telephone (14 percent) services. Hence for many users, those not requiring coverage in large urban areas, compatibility with a terrestrial type of system is not necessary. This allows the possible use of more power and spectrum efficient modulation formats and is expected to lead to substantially reduced cost of service.

5.6 FUNCTIONAL REQUIREMENTS

In the companion "MSAT Commercial Viability Study", the functional requirements for both MTS and MRS mobile terminals were addressed. A discussion of these findings can be found in Task 2 para. 2.7.0 of Ref.1. For convenience a summary of these findings is included in Table 2.

As part of the MSAT Commercial Viability Study a total system concept was developed. This is reported in the Final Report of Ref.1. The basic concepts from this report are illustrated in Figures 1 and 2.

	MTS	MRS
Grade of service (blocking at end of life)	0.1	0.01 emergency dispatch 0.15 non-emergency dispatch. Average 0.048
Quality of service	Toll, 26 dB subjective S/N	Communication, 20 dB subjective S/N
Number of channels	134 or greater	829 or greater
Service area	Nationwide	50 to 700 miles
Mode	Full duplex	Half-duplex
Automatic identification	Essential	Essential
Automatic location	Phase ranging capability essential for AMPS compatibility	Not required

Table 2. Functional Requirements Summary, Mobile.

Table 2 (cont'd)

	MTS	MRS
Modulation (voice)	NBFM(12)	NBFM(12), NBFM(5), SSB, ACSSB or LPC (T.B.D.)
Modulation (data)	10 Kbps FSK	10 Kbps binary FSK, 4.8 Kbps QPSK or 2.4 Kbps BPSK T.B.D.
Selective calling	Essential, 10 digit	Essential, 6 + 4 digit
Frequency control		
(access)	Scanning synthetisizer	Scanning synthesizer DAMA synthesizer
(voice)	DAMA synthesizer	DAMA synthesizer
Registration	Automatic with manual override	Manual
Security	Capability using external device	as MTS
Privacy	DAMA only access to voice channels	as MTS

Table 2 (cont'd)

	MTS	MRS
Frequency range (Provisional FCC)	Tx 821 to 845 Mhz Rx 866 to 890 MHz	Tx 821 to 825 MHz Rx 866 to 870 MHz
(Provisional DOC/NASA)	Tx 821 to 851 MHz Rx 866 to 896 MHz	Tx 821 to 831 MHz Rx 866 to 876 MHz
Dialling	Keypad entry (optional rapid)	Preset rapid dial (optional key pad)
Radiated power control	Essential for AMPS compatibility	Not required
Voice processing	2:1 Syllabic compandor	T.B.D.

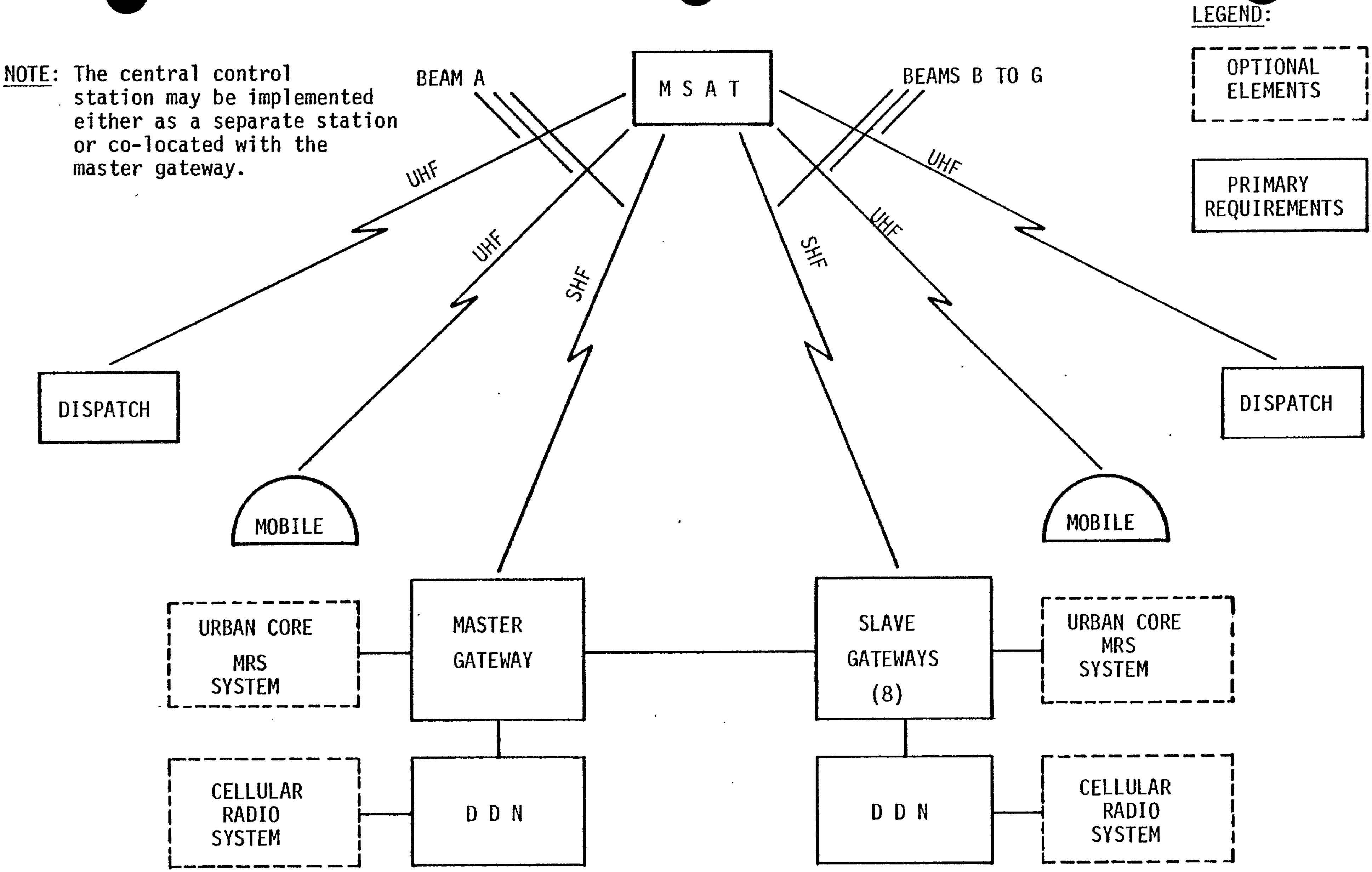
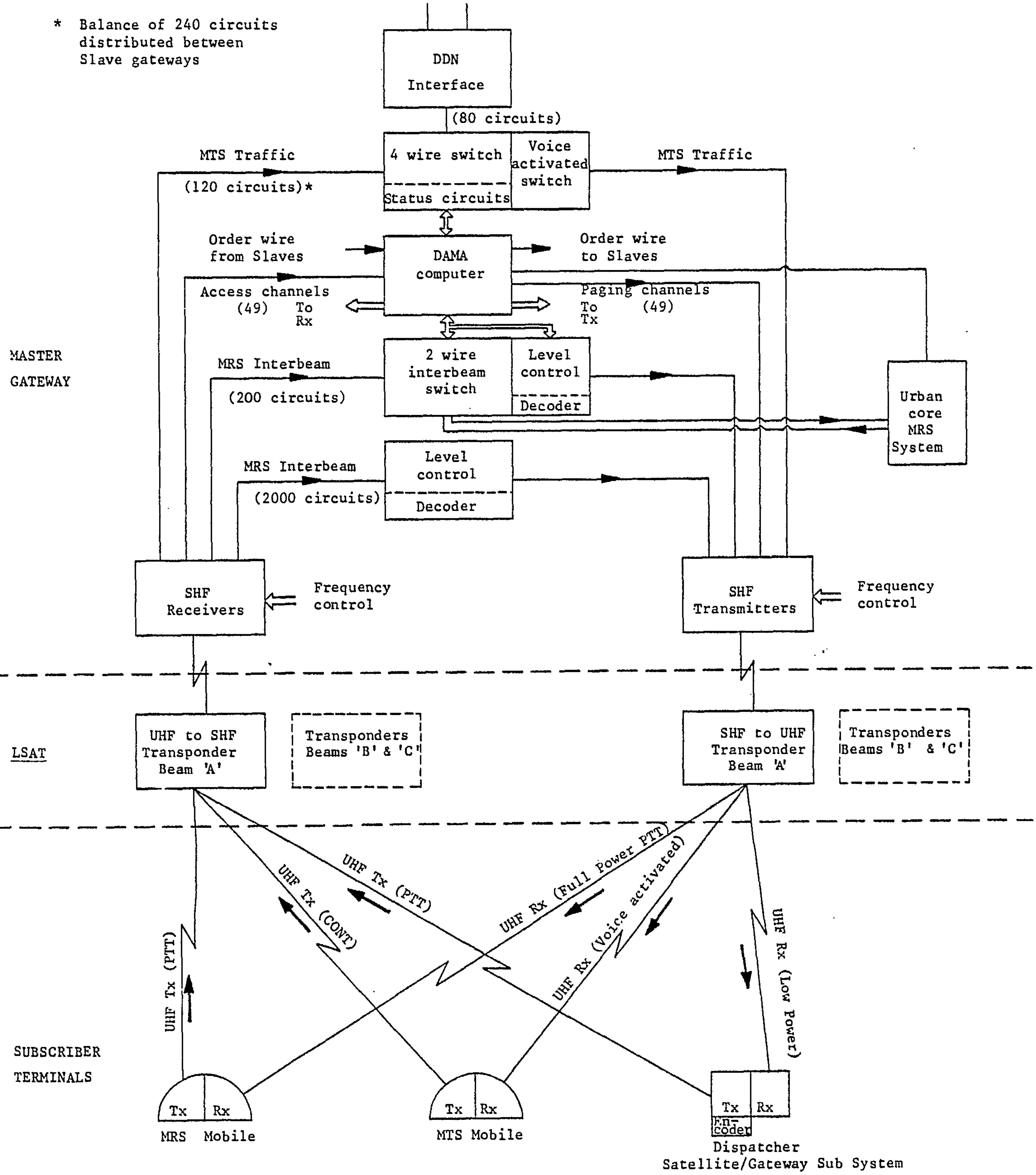


FIGURE 1. GENERAL CONFIGURATION INTEGRATED SYSTEM



SIMPLIFIED FUNCTIONAL DIAGRAM

FIGURE 2

6.0 PERFORMANCE REQUIREMENTS FOR MSAT MOBILE TERMINAL

In the preceding section the functional requirements for an MSAT mobile terminal were introduced. In this section the general performance requirements are introducted from which are derived the specific performance requirements for the different modulation modes.

It will be seen that, as a result of the more or less fixed location of the satellite with respect to the mobile, the more severe performance requirements are related to power output, receiver noise figure and frequency stability.

This differs from the requirements for a terrestrial service mobile where dynamic range, spurious and harmonic rejection and good intermod performance are predominant requirements see (Section 6.2).

6.1 MOBILE TERMINAL SATELLITE SERVICE

6.1.1 Mobile Transmitter Power Output

The mobile transmitter power may be calculated using equation (1):

$$Pm(dBw) = C/No + Pl + Pf + FM - G/T - Gm - Gs\ (EOC) - 228.6 \quad (1)$$

where C/No is assumed 1.5 dB greater than C/(No + I)

Pl = Feeder losses, 2dB satellite 1dB mobile

Pl = Path losses, 183dB

G/T = Satellite receiver -27dB/K

Gm = Mobile antenna gain, 4dB

Gs(EOC) = Satellite antenna gain

FM = Fade margin 13dB

From Figure 3 the minimum C/(No + I) requirements are for various modulation schemes and speech quality objectives are shown in Table 3.

MODULATION	BANDWIDTH OR DATA RATE	C/(No + I)(dB Hz)	
		MTS	MRS
NBFM(12)	30 KHz	53	51.6
NBFM(5)	12.5 KHz	52	49
ACSSB	5 KHz	48(43)*	45(40)*
RELP	4.8 Kbps	--	45
LPC 10	2.4 Kbps	--	42

Table 3. Minimum Carrier/Noise Density Ratio

* Average sideband powers and not carrier power is given for ACSSB.

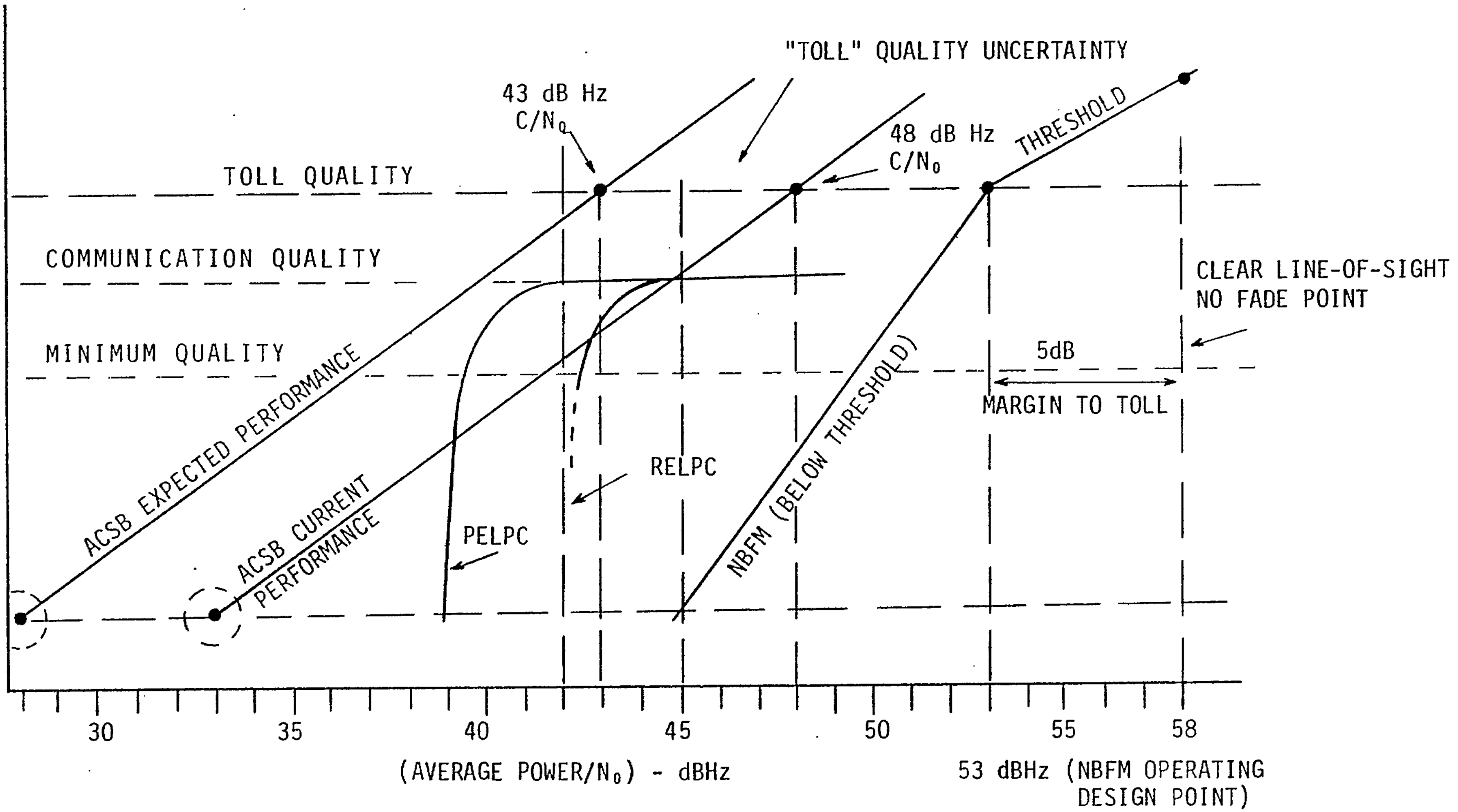


FIGURE 3. VARIATION SPEECH QUALITY WITH C(No + I)

NOTE: Actual levels will vary depending upon particular implementation technique.

From Figure 3 it can be seen that the C/(No + I) margin between acceptable speech quality and minimum speech quality varies considerably for the different modulation schemes.

The margin for LPC is considered too low for an operational system and a greater margin, as obtained for ACSB, should be applied to all modulation modes. The resulting design (C(No + I)) objectives as presently envisaged by Department of Communications are shown in Table 4.

MODULATION	BANDWIDTH OR DATA RATE	C/(No + I) (dB Hz)	
		MTS	MRS
NBFM(12)	30 KHz	53	53
NBFM (5)	12.5 KHz	52	52
ACSSB	5 KHz	48	48
RELP	4.8 Kbps	----	50
LPC 10	2.4 Kbps		47

Table 4. Design Objectives Carrier/Noise Density Ratio.

The effect of satellite antenna size upon the required mobile transmitter power is shown in Table 5.

ANT.SIZE(FT.)	30		50		83	
EOC GAIN(dB)	33		36.5		39	
SERVICE	MTS	MRS	MTS	MRS	MTS	MRS
NBFM(12)	15.4	15.4	11.9	11.9	9.4	9.4
NBFM(5)	14.4	14.4	10.9	10.9	8.4	8.4
ACSSB (Average power)	10.4	10.4	6.9	6.9	4.4	4.4
RELP	----	12.4	----	8.9	----	7.4
LPC	----	9.4	----	5.9	----	3.4

Table 5. Design Objectives Mobile Power Requirements (dBW)

6.1.2 Receiver Noise Figure

From the statement of work and referenced documents the MSAT system objectives are for a mobile terminal G/T of -25.5 dB/K. Assuming a 4 dBi gain antenna, a 1 dB feeder loss and 700 degrees antenna noise this equates to an effective receiver noise figure of 2.2dB.

6.1.3 Bandwidth

The total bandwidth required is dependent upon the overall number of channels required to serve the projected traffic. This in turn is dependent upon the beam configuration, the frequency reuse pattern, and the channel bandwidth. It can be seen from Ref.1, Final Report Table G that for the 7-beam operational MSAT, in which channels are reused every third cell, 1026 channels are required.

By assigning groups of MTS and MRS channels in the ratio of the projected traffic, 14:86, the requirements for an MTS terminal is approximately 144 channels and for MRS 882 channels. Using a 30 KHz channel bandwidth for MTS and 5 KHz for MRS the use of ACSSB or LPC gives a bandwidths of 4.32 MHz and 4.41 MHz respectively for a total bandwidth of 8.74 MHz. If the MTS is provided through the use of ACSSB then the MTS bandwidth becomes 0.72 MHz and the total bandwidth is reduced to only 5.13 MHz. In practice guard intervals are required between the beam sub-bands so that the overall bandwidth is expected to be 5 MHz for each of the MTS and MRS bands.

6.1.4 Selectivity and Dynamic Range

The signals received at a mobile receiver due to the satellite down link all propagate along the same paths and would therefore normally be received at the same level. Over the 5.0 MHz bandwidth of interest, frequency selective fading, due to multipath transmission, will arise where the differential path length exceeds 30 metres. This is most likely to occur when mobiles are located on higher ground surrounding lakes or flat areas of snow. Although frequency selective fading within the band width of interest is not expected to be experienced very frequently some provision must be made. In this case studies by DOC indicate the fade margin of 5dB, as allowed in the forward link budget, would be adequate.

The uplinks to the satellite however are distributed across a beam and each is subject to different signal path variations. A fade margin of 13dB has been estimated to which must be added a further 3dB due to mobile location with respect to the satelite antenna pattern.

At the satellite, and hence at the mobile receiver, this gives rise to a possible signal strength variation across the band of 16 dB due to the uplink plus 5 due to forward link for a total of 21dB.

In an MSAT system providing both telephone and radio services using NBFM and LPC respectively there would, normally, be a signal strength variation of 6 dB. Possible improvements in ACSB or LPC may ultimately increase this to 11dB. Thus the total signal strength variation across the band as seen by the mobile receiver would be as high as 16 + 5 + 6(or 11) = 27(or 32dB).

Assuming signals originating in terrestrial systems do not fall in the MSAT band, the receiver system adjacent channel selectivity and spurious responses need only be 27dB greater than the signal to noise objective. For NBFM the C/No of 53dB equates to C/N of 10dB, hence adjacent channel and spurious power must be attenuated by 37 dB. For LPC the equivalent value is 39 dB.

Assuming all signals received within the MSAT band originate from the satellite, the requirements for intermodulation performance are easily met. It was shown above that the maximum variation in signals is only 27dB. Thus for a wanted signal of -120 dBm, intermod due to two signals at -93dBm should be attenuated by -37dB. This is equivalent to a third order intercept of only -83dBm.

Also, as a result of the small dynamic range of signals within the MSAT system, the transmitter sideband splatter and spurious within the MSAT band need be only 37dB below the carrier output to prevent degradation of signal quality in adjacent channels of the MSAT system. Clearly however the transmitter must meet the minimum requirement of RSS 119 for spurious outputs outside of this band in order to prevent degradation of other terrestrial receiving systems.

6.1.5 Signalling

Within the MSAT only system the primary signalling requirements are for:

- paging, incorporates a unique vehicle identity number,
- access, also incorporates a unique vehicle identity number,
- paging acknowledgement, a modified access signal,
- access acknowledgement, a modified paging signal,
- dial, busy, ringing, and related status tones,
- dialled number,
- voice channel allocation,
- call termination,
- radiated power control (optional).

To minimize the signalling burden, signalling rates should be as high as economically and technically feasible within the channel bandwidths. For MTS application using NBFM, compatibility with cellular systems can be obtained through the use of a 10 Kbps FSK modulation scheme. For ACSSB and LPC, using channel separations of 5 KHz and bandwidths of 3 KHz, a data rate of 2.4 Kbps using DQPSK or MFSK is more likely to prove optimum. In both cases it must be expected that some form of AFC will be necessary to compensate for Doppler shifts and system frequency errors if the demodulator performance is not to be severely degraded. Similar AFC will be needed to track the signal within the objective of

+/-20 Hz for the voice mode of ACSSB.

In principle the signalling functions may be conducted on either a dedicated signalling channel (or small group of channels) or distributed over all voice channels. The signalling may also be conducted on a full duplex basis, thus minimizing delays due to switching, or in a half duplex mode. The latter is potentially attractive for MRS applications as the requirements for a mobile duplexer may be relaxed thus resulting in mobile cost savings. The signalling protocols however become more restrictive and must be carefully evaluated.

It is generally considered that for systems using more than about 10 voice channels it is more efficient to use a small set of dedicated signalling channels rather than superimpose the signalling on the voice channels. This arise due to the much higher data rates that may be accommodated with relatively unsophisticated modems when interference to and from the voice modulation can be neglected. The dedicated channel concept is considered most likely to be implemented by MSAT.

a) MTS Protocols

For the mobile telephone service it is desirable that the mobile terminal operates in a full duplex mode and also should be compatible with the terrestrial AMPS system. In some respects the signal formats and protocols developed for AMPS appear suitable for MSAT. The notable exceptions include:

- Access busy signal, in the terrestrial systems immediately one mobile captures the access channel a busy signal is transmitted to all other mobiles. This prevents other mobiles from using the access channel and reduces the incidence of access collisions. Due to the long propagation delays over a satellite service this mode is not effective. The alternative modes of contention access, reserved access, time ordered access, polled access either require additional access channels or result in excessive delays. Typically for 2800 MTS mobiles per beam, time or polled access would result in maximum delays of up to one minute when using a single channel per beam and a 200 bit access word. The average delay is 30 seconds.

  For most of the system life however the traffic carried by MSAT is considerably below the design capacity. Hence a time ordered or polled access system with average delays not exceeding 30 seconds in the final year may prove acceptable for the MTS user. Within such a system it would be possible to provide priority users with a shorter access time for which a small additional tariff would be charged.

Supervisory Audio Tones (SAT); in the AMPS systems supervisory audio tones generated at the base station are repeated by the mobile. Non-detection of the SAT by either mobile or base station is used to initiate call termination and provide muting of audio (replaces normal noise squelch).

In the MSAT system voice activation in the forward direction to the mobile is expected to be used to conserve power in the satellite. As this prevents the use of SAT in the manner employed in the AMPS system, protocols must be changed or alternatively SAT generated by the mobile. For mobile receive, the mobile would need a fast acting noise operate squelch to replace SAT for purpose of muting the audio output during pauses in speech.

The following Table 6 is an attempt to show parameters that are compatible, or may be made compatible with relatively little effort, between cellular and satellite mobile telephone systems. The cellular parameter identification has been extracted from "Cellular System Mobile Station - Land Station Compatibility Specification. Working Paper No.2 Issue B. March 1981. Prepared by the EIA (TR-8) Ad Hoc Committee on Cellular Standards." Other parameters will need in-depth study for compatibility or modification.

EIA SPECIFICATION PARAMETER	COMMENTS
Security and Identification of Mobile	
Mobile Identification Number	34 bit binary number
Serial Number	32 bit binary number
Station class mark	4 bit binary number
Supervision	
Malfunction Detection	
Malfunction timer	Status check maximum time with no correct response 60 seconds transmitter shutdown.
False transmission	To prevent component failure causing transmission.
Call Processing	
Initialization:-	
Update overhead information	All messages must be correct and all messages intrain received before proceeding.

Table 6. Summary AMPS of Signalling Protocol Functions. (Sheet 1 of 4)

Table 6 (cont'd)

E1A SPECIFICATION PARAMETERS	COMMENTS
Paging channel selection	Examine all channels for signal strength and proceed.
Verify overhead information	Tune to strongest channel and await, within three seconds overhead message train given proceed.
<u>Idle</u>	
Response to overhead information	Check for requirement and proceed.
Page match	To confirm channel and activity.
Order	Control function.
<u>System Access</u>	
Set access parameters	Sets timer dependent on function.
Scan access channels	Examine all channels. Select and attempt access to strongest channel.

Table 6. Summary AMPS of Signalling Protocol Functions. (Sheet 2 of 4)

Table 6 (cont'd)

E1A SPECIFICATION PARAMETERS	COMMENTS
Retrieve access attempt	Maximum seizure or busy attempts limited to 10.
Update overhead information	1.5 second maximum task attempt time.
Seize reverse control channel	Idle-busy identification and action.
Delay after failure	access control timer to establish re-attempts.
Service request	Demand for service.
Await message	Places mobile in await mode (5 second waiting time).
Await registration message	Service request await mode (5 second waiting time).
Alternate access channel	May access second strongest channel.
Directed re-entry	Re-attempt to acces strongest of two channels.

Table 6. Summary AMPS of Signalling Protocol Functions. (Sheet 3 of 4)

Table 6 (cont'd)

E1A SPECIFICATION PARAMETERS	COMMENTS
<u>Mobile Station Control on the Voice Channel</u>	
Loss of radio-link continuity	If signal is lost for five seconds re-establishes system contact.
Confirming initial voice channel	Check for correct operation.
<u>Alerting</u>	
Waiting for order	Holding mode for control function.
Waiting for answer	Holding mode for central function.
Conversation	Initiates activity.
<u>Signalling Formats</u>	Needs further investigation.

Table 6. Summary AMPS of Signalling Protocol Functions. (Sheet 4 of 4)

b) MRS Protocols

For MRS, the expected use of half duplex narrow band modes of operation together with short message durations precludes the use of the signal formats and protocols developed for AMPS.

Fortunately the information to be transmitted is somewhat less than for the MTS. This arises as mobiles will generally talk to one of only a few dispatch points. Thus the called address can probably be reduced to a two digit number rather than the ten digits used in the MTS. Similarly the mobile address need not have a telephone type number. Nevertheless it must be long enough to accommodate the projected 140,000 users. A six digit number would appear to be adequate. Even so at a 2.4 kbit data rate the preamble, address and ID will likely require a minimum of 64 bits and if error protection is included 96 bits. At 2.4 kbit/second, 96 bits requires a transmission time of 40 milliseconds. From this it is evident that access delays could be greater than the average message length except through the use of numerous access channels or highly efficient random access protocols.

The simple ALOHA protocol used by many satellite systems has an efficiency of only 18 percent. In the double hop mode half duplex mode envisaged for the MRS, this efficiency can be expected to be even lower. Slotted ALOHA can result in improved efficiency of up to 36 percent and the various reservation systems can improve efficiency and reduce delays of the bid time is short compared with the message length. This is unlikely to be the case for mobile radio service.

In summary, although less than ideal, the slotted ALOHA protocol, or a derivation thereof, appears to be workable for the MRS but will require further study.

6.1.6 Frequency Stability

The end to end frequency error permissible within the system is dependent upon the mode of modulation.

For FM the principle cause of signal degradation is the non-symetric attenuation of the signal sidebands due to the IF filter. To maximize the carrier to noise ratio however, the IF bandwidth should not exceed the sideband bandwidth by more than about ten percent, hence the maximum frequency error should not exceed +/-1 KHz for a 30 KHz system.

For SSB the recovered audio frequency is offset from the correct frequency by the system frequency error. It is normally accepted that maximum error should not exceed +/-20 Hz. As this is not readily accomplished with economic oscillators it is normal to utilize a phase lock technique in association with a pilot carrier. The capture range for such loops can be as wide as the channel but at the expense of longer capture times or greater oscillator wideband noise. A typical design figure for capture range is +/-150 Hz.

The main sources of frequency errors are Doppler shift and instability of the local oscillators in the gateways, satellite and the mobile terminal.

Doppler shift is caused by the relative motion of the satellite to the gateways and by the movement of mobiles relative to the satellite. In the case of the gateway/satellite component the precise values will be different for each gateway. However it is possible, by a suitable adjustment of a particular gateway transmit or receive frequency, to compensate completely for the Doppler component at that gateway through the use of an automatic frequency control loop operating through the satellite back to the gateway. The same loop also provides frequency compensation due to errors in the gateway and satellite.

In the case of the mobile, the frequency error is obviously different for each mobile. There is no known/simple or economic way for this component of Doppler shift or frequency error to be compensated.

Table 7 indicates the frequency errors resulting from typical state-of-the-art local oscillator systems and Doppler shift in the gateway, satellite and mobile.

SOURCE	FREQUENCY ERROR
Gateway Tx at 12 GHz at +/-3 x 10 exp-9	+/- .036 KHz
Satellite Osc. at 12.8 GHz at +/-1 x 10 exp-6	+/-12.8 KHz
Mobile L.O. at 800 MHz at +/-2.5 x 10 exp-6	+/- 2.0 KHz
Doppler SAT/mobile (mobile at 100 Km/hr.)	+/- 0.076 KHz
Doppler SAT/gateway due to 12 GHz backhaul	+/- 1.2 KHz
Total	+/-16.112 KHz

Table 7. Sub-system Frequency Errors.

Clearly from Table 7 it can be seen that provision must be made within the system for some frequency compensating technique if the objectives determined earlier are to be satisfied.

The frequency error contribution due to the satellite and gateway can be compensated for through the use of a spectrum centering pilot tone feedback to the gateway. For FM the residual error of +/-2.076 KHz would normally be accommodated through the use of larger IF bandwidths or a small improvement to the stability of the mobile equipment. For SSB a frequency correction circuit will be necessary at both the mobile and for each channel of the frequency demultiplexer in the gateway. The contribution due to the mobile will require correction through the use of an AFC or a phased lock loop in both the mobile and SHF down convertors at the gateways. As this would need to be applied independently to each channel, the equipment complexity at the gateway would be significant.

The permissible frequency errors on FM are such as to permit the use of mobile terminal oscillators having a short term stability over the temperature range of +/-2 parts/million.

Once aged, normally about six months, the long term drift can be expected to be small compared to the short term instability of +/-2 parts/million. Adjustment to compensate for long term drift would be made during routine maintenance of the mobile.

For ACSB or LPC the more stringent requirements on frequency stability will probably necessitate the use of preaged oscillators in the mobile terminal.

6.1.7 Step Size

Due to the large number of channels required the use of frequency synthesized mobile equipment can be expected. For FM modes of modulation the channel spacing used in the AMPS system of 30 KHz should be anticipated thereby requiring a 30 KHz step size.

For ACSB or LPC a 5 KHz channel spacing is anticipated and requires a 5 KHz step size. It was shown earlier however that some form of frequency correction would be required. A convenient manner of performing frequency correction would be by means of a digital compensation technique within the synthesizer. This approach has the advantage that it can be used for both receive and transmit even in a half duplex mode of operation. Strong consideration should therefore be given to a providing a step size of 20 Hz. This would allow digital frequency compensation to within the +/-20 Hz maximum frequency objectives for ACSB.

6.2. MOBILE TERMINAL, SATELLITE/TERRESTRIAL SYSTEM COMPATIBLE

In this sub-section the requirements for a terminal capable of operating in both the terrestrial and and satellite components of an integrated system are considered.

6.2.1 Power Output

The line-of-sight propagation characteristics pertaining to the high UHF band means that the operating range is effectively limited by topographical features and exhibits a sharp cutoff in areas shadowed by such features. Within the unobstructed line-of-sight areas it is generally possible to achieve a high carrier to noise ratio without recourse to excessively high and costly transmitter powers. This is clearly illustrated in the following example.

Example of Terrestrial Path Losses

Assume an unobstructed mobile to base range of 30 kilometres, and actual antenna elevations of 2 and 68 metres respectively; this translates into effective antenna heights of 2 and 24 metres:

Plane earth path loss 90 percent locations	141 dB
Fade margin 99 percent reliability	20 dB
Total losses	161 dB

Base station antenna gain of	8.9 dB
Base station coupler and feeder losses of	5.4 dB
Receiver G/T	-28 dB/K^{o}

Hence from equation (1) (see 6.1.1) -28 dB/K

Required mobile EIRP at

(53 dB C/No for NBFM(12) = 9.9 dBw)

and for (48 dB C/No for ACSSB) = 4.9 dBw average

Therefore,

Mobile transmitter power NBFM(12) = 9.8 watts

ACSB = 3 watts

It is noted that for multisite cellular systems a smaller range and fade margin is normally assumed. Hence the power output for AMPS compatible radios is limited by the EIA spec to 6.3 watts and for planned production units a 3-watt output is anticipated.

6.2.2 Receiver Noise Figure

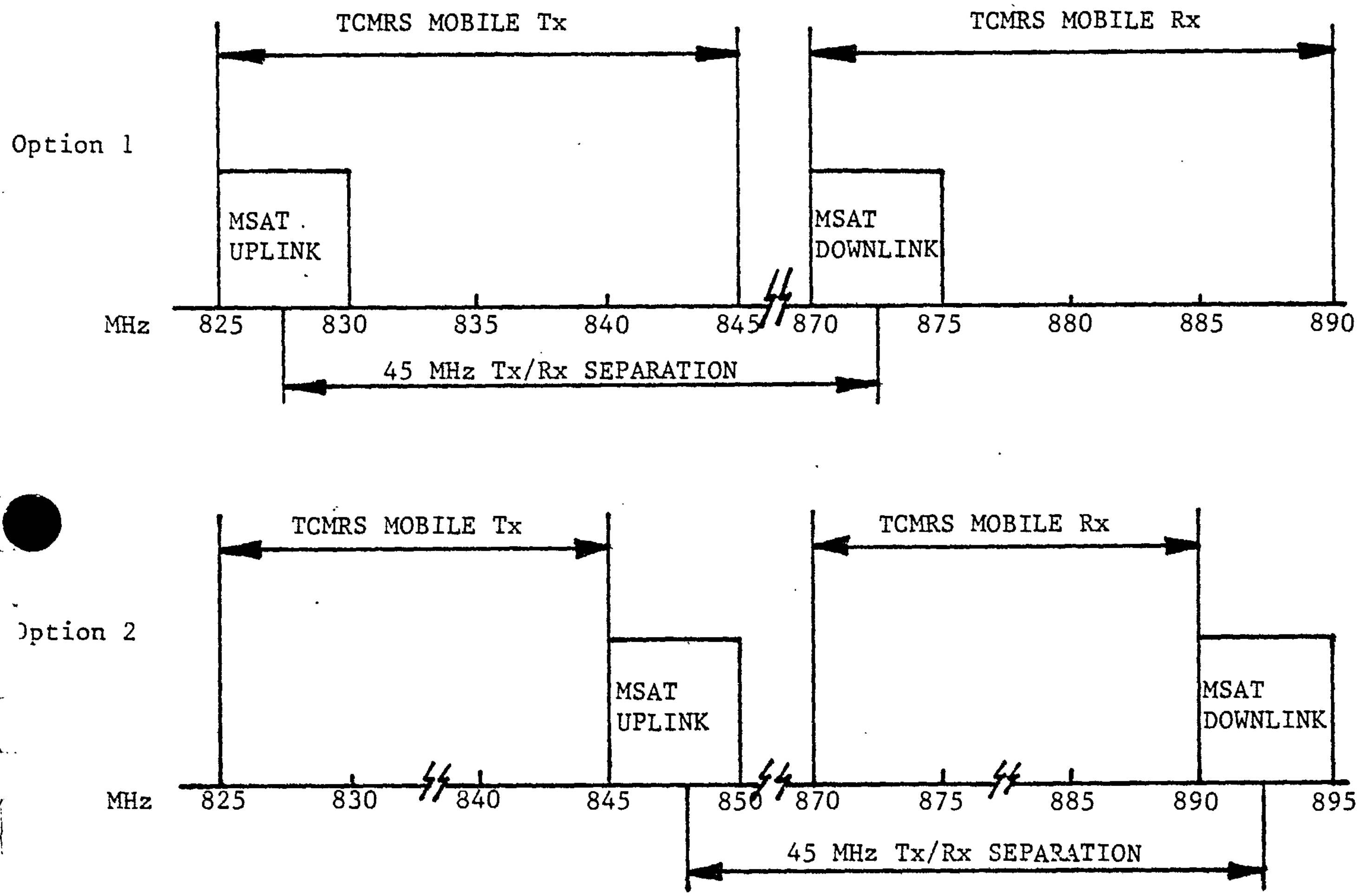
Receivers operating in urban terrestrial systems usually operate in a higher noise and signal environment than the signals obtained from MSAT. Most modem designs sacrifice sensitivity to obtain good intermod and spurious protection. Noise figures range from about 5 dB when using an RF amplifier to about 9 dB. Hence the 2.2 dB noise figure objective for MSAT terminals would be compatible with terrestrial applications.

6.2.3 Bandwidth

For a Northern Canada only satellite service, frequency co-ordination on a Canadian only basis may permit some interleaving of MSAT and terrestrial channels. Due to the overlap of antenna footprint into the U.S.A. however, it must be expected that frequency co-ordination will be required with the U.S.A., in which case, separate terrestrial and satellite service RF sub-bands should be anticipated. For compatibility with both MSAT and terrestrial systems the mobile terminal bandwidth should therefore be equal to the sum of the individual bandwidths.

For use in the cellular systems within the U.S.A. provisional planning by the FCC has been based upon a total bandwidth of 40 MHz, i.e., 20 MHz each for mobile transmit and mobile receive, using 660 duplex channels at 45 MHz separation. This has been shown (Ref.3) to be adequate without frequency reuse for cities of size up to about two million. In Canada it is not unreasonable to assume that a cellular system will closely follow the performance parameters of the U.S.A. cellular systems and hence mobile terminals would have a similar 20 + 20 MHz bandwidth. In this case the total bandwidth for an MSAT /AMPS compatible terminal should be 20 + 5 MHz for each of the transmit and receive channel groups.

Two optional frequency plans are shown in Figure 4. Option 1 assumes that the 5 MHz for MSAT is contained within the cellular band and option 2 assumes the additional 5 MHz bandwidth.



Candidate MSAT Frequency Allocations

FIGURE 4

In Annex A to Task 1, of the Commercial Viability Study, it was shown that using the projections from the traffic survey that only 246 Erlangs of MTS traffic could be expected in the largest Canadian cities of 2.5 million people. This requires approximately 260 channels at ten percent blocking and hence only 7.8 MHz for each of the transmit and receive components; not the 20 MHz as planned for allocation in U.S. cellular systems.

This latter figure would greatly assist in the achievement of a compatible MTS terrestrial/MSAT mobile for use in Canada as cellular equipment already provides a 20 MHz bandwidth on both transmit and receive.

For use in terrestrial MRS system the Commercial Viability Study shows a requirement for only 155 channels to serve the cores of urban areas.

Using ACSB or LPC modulation the total bandwidth required in only 0.575 MHz and is easily compatible with the 5 MHz required for MSAT.

6.2.4 Selectivity and Dynamic Range

In general terrestrial system mobile receivers may be simultaneously illuminated by signals from a multiplicity of sources so that, depending upon the particular paths, signal strengths may exhibit variations in excess of 100 dB although for much of the time the variation could be expected to be not greater than 70 to 80 dB. In many commercial mobile designs, cost considerations frequently result in a compromise between receiver noise figure in order to achieve the required dynamic range and selectivity. This is possible because system coverage is influenced to a much greater extent by propagation paths than by receiver sensitivity.

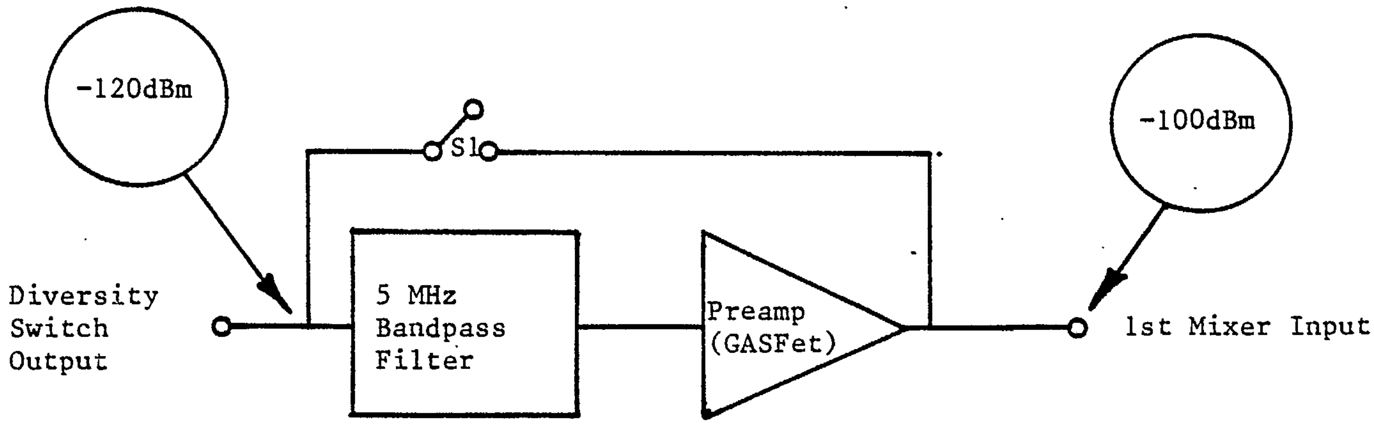
Within an integrated terrestrial satellite system both immunity to interference and receiver sensitivity must be optimized. Fortunately the coverage areas of the two components of the system may be separated and in the satellite coverage areas all unwanted signals will exist at a fairly low level. Thus a switched mode of operation may be possible in which a pre-amp, used to achieve good noise figure in the satellite coverage area, is bypassed to achieve good dynamic performance in the terrestrial system coverage area. (See Figure 5)

6.2.5 Signalling Protocols

The small coverage area of terrestrial base stations with respect to satellite antenna footprint requires that the signalling system frequently perform additional hand-off functions during the course of a conversation. This necessitates determining the approximate location of a mobile with respect to the surrounding base stations. The actual hand-off function usually entails a change of the operating voice channel so that it is necessary to provide signalling on the voice channel in use. In the AMPS system this is accomplished through utilization of high speed data burst which produces minimum disturbance to the voice channel.

For purposes of paging and access the short range makes it possible, through the use of a channel busy flag, to utilize efficient paging and access protocols.

Note: S1 Closed for terrestrial system



Implementation of MSAT Preamp

FIGURE 5

A a result of the short range, however, the paging protocols must either permit simultaneous transmission from all sites or be based upon frequent updating of the vehicle location on an automatic basis. The latter, known as automatic registration, can impose a significant loading on the system.

The detailed formats and protocols for AMPS compatible mobiles are specified in the EIA working paper TR.8 Issue B prepared by Ad Hoc Committee on Cellular Standards. This paper expected to become EIA PN 1377. The key features were identified in Table 6 (See Section 6.1.7 a)).

6.2.6 Frequency Stability

Frequency stability requirements for the mobile terminal in a terrestrial system are essentially the same as for a satellite system.

6.3 SUMMARY

From the independent analysis of requirements for a mobile terminal to operate only via satellite (Section 6.1) and via either satellite or terrestrial system, the specific requirements for FM, ACSB and NB digital voice mobile terminals were developed. These requirements, included in Vol. II of this report, were circulated to industry for purposes of obtaining specific costing estimates for the various options.

7.0 INDUSTRY SURVEY

Through frequent contact with manufacturers and from the results of an industry survey, the present and near term availability of mobile terminal and associated technology suitable for development of an MSAT capable mobile terminal has been determined. The sources identified are shown in Table 8. (The product and status codes used in Table 8 are shown in Table 9.)

It should be noted that only those companies from which a positive indication of product capability or market intent was obtained are shown in Table 8. Non-inclusion in the table does not necessarily infer that a company does not produce, or intend to produce, the products identified.

Canadian Sources	Product Code	Product Status
Canadian Marconi	800 MRS/TRN/CELL	PP
	800 ACSB/LPC	PP
Lenbrook Industries	800 MRS/TRN/CELL	PP
	800 ACSB	PP
Canadian General Electric	800 MRS/TRN/CELL	PP
Canadian Motorola	800 MRS/TRN/CELL	PP
Racal Canada	800 ACSB/LPC	PP

Table 8. Listing of manufacturers and their advanced technology mobile product lines. (Sheet 1 of 3)

ACRONYMS

Existing product line	IN
Production engineering complete	PE
Development stage	D
Product planning stage	PP
Trunk system mobile	TRN
Cellular system mobile	CELL

U.S. Sources	Product Code	Product Status
E.F. Johnson	800 MRS/TRN	IN
	800 CELL	PE
	150/400/800 ACSB	PP
Motorola Inc.	800 MRS/TRN	IN
	800 CELL	PE
Harris	800 MRS/TRN	IN
	800 CELL	PE
General Electric	800 MRS/TRN	IN
	800 CELL	PE
Sideband Technology	150 SSB	IN
	150 ACSB	D
	450 ACSB	PP
Stevens Engineering Assoc.	150 SSB	IN
	450 SSB	D
Time and Space Processing	LPC	IN/PP

Table 8. Listing of Manufacturers and their advanced technology mobile product lines. (Sheet 2 of 3)

Japanese/European Sources	Product Code	Product Status
OKI	800/CELL	PE
NEC	800/CELL	PE
Fujitsu	800/CELL	PE
Hitachi	800/CELL	PE
Philips	150/450 ACSB	PE
Racal	LPC	PP

Table 8. Listing of Manufacturers and their advanced technology mobile product lines. (Sheet 3 of 3)

PRODUCT TYPE	PRODUCT CODE
806 - 890 MHz MRS conventional mobile	800 MRS
806 - 890 MHz MRS trunked mobile	800 TRN
806 - 890 MHz MTS cellular mobile	800 CELL
SSB VHF mobile	150 SSB
ACSSB VHF mobile	150 ACSB
ACSSB Low UHF mobile	400 ACSB
LPC speech processor	LPC
RELP speech processor	RELP

Table 9. Product and Product Status Codes.

7.1 RESULT OF SURVEY

The survey of existing and planned mobile terminals, failed to identify any specific products that satisfy the functional and performance requirements identified in Section 6 for any of the three modulation modes. Moreover no specific products were identified as being easily modified to satisfy these functional and performance requirements within the physical and thermal constraints of existing designs.

This arises primarily from the highly developed packaging and styling of land mobile radio equipment which precludes the inclusion of any but very minor modifications.

A discussion of the difficulties involved in extending the present level of performance to satisfy the MSAT requirements follows in Section 8.0.

From Section 8.0 it will be seen that for NBFM the developments required do not necessarily require an extension to the state-of-the-art. However considerable product engineering is required to build all of the capabilities into an economical mobile package. It is probable that on an interim basis these performance enhancements could to a large extent be accommodated through the use of an external box. However the resulting package would probably be more expensive than a single package as it would still require some modification to the basic unit.

In discussions with industry very little enthusiasm could be found for the development of an NBFM mobile for MSAT application either in Canada or in the U.S.A. In general this is perceived to be due to the massive investment made by industry into the cellular radio systems. Any alternative such as MSAT is seen as a dilution of the market and available engineering resources.

The introduction of the idea that MSAT could perform a valuable bridging function, to extend coverage between cellular systems, did produce a more positive reaction. This was insufficient, however, to give confidence that any of the major manufacturers would wish to divert effort toward the development of an NBFM MSAT mobile terminal.

In Canada; Lenbrook Industries indicated their willingness to assemble MSAT terminals in production quantities but they would rely upon E.F. Johnson for development.

It is shown in Section 8.0 that the development of commercially successful ACSB at 800 MHz or narrowband digital voice terminals at any frequency is still subject to advances in the state-of-the-art. However, as in the case of NBFM, engineering evaluation units could be assembled from components existing in today's technology.

Ongoing development for other applications is expected to continue so that by the time of the launch of an operational MSAT satellite, suitably engineered products could be available for use in the land mobile application.

Among the large manufacturers, because of heavy commitments to NBFM, again little enthusiasm could be found for either alternative. However, some of the smaller companies in the field of mobile radio were more enthusiastic. The main reason for their interest in the non-NBFM terminals is that it provides a field in which they compete at an equal level with the major companies. In particular Canadian Marconi and Racal Canada have shown a major interest in the development of any new mobile which potentially allows leap frogging into the generation of mobile terminals and systems beyond cellular and NBFM radios.

Other companies expressing a strong interest were Lenbrook Industries, Westech, Glenayre (mainly for control loads and logic functions), and Mitel (mainly in the field of advanced component development and supply).

8.0 CURRENT EQUIPMENT PERFORMANCE AND DEVELOPMENT IMPLICATIONS

For ease of understanding of the following discussion the reader is referred to the block diagrams for:

	FIGURE
NBFM(12) AMPS Compatible Mobile Terminal	6
NBFM(12) MSAT Mobile Terminal	7
NBFM(12) MSAT/AMPS Compatible Mobile Terminal	8
ACSB MSAT Terminal	9

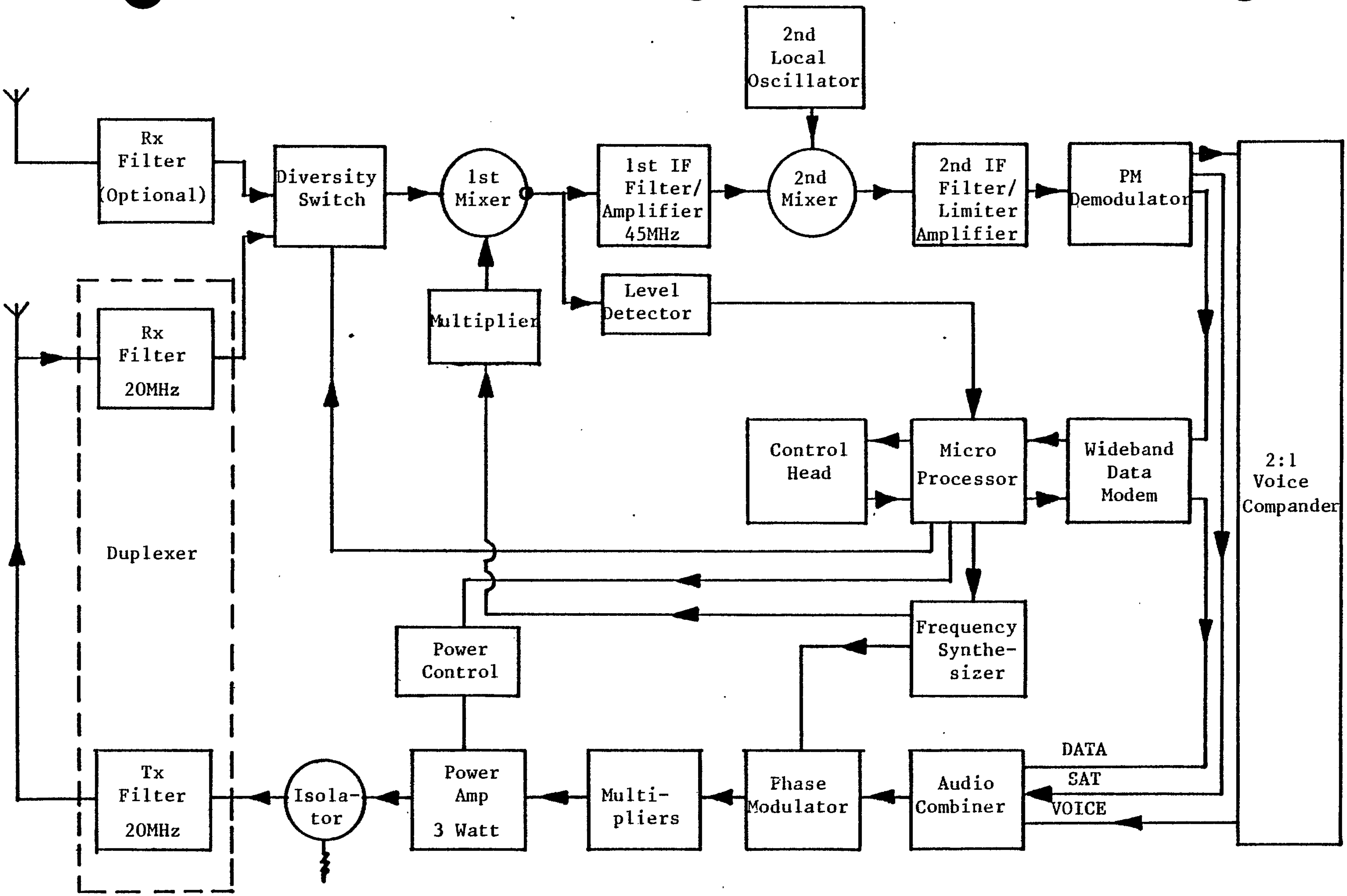
8.1 POWER OUTPUT

a) FM

Single ended class "C" power amplifiers as used in FM mobile terminals are available at power outputs of up to 35 watts. In the half duplex FM mode of operation the major performance parameters of concern are efficiency, harmonic and intermodulation distortion, and VSWR protection. These parameters have impact upon the heat sink and hence equipment size, spurious outputs, sideband splatter and equipment reliability.

Increasing the power to 50 watts is expected to require the use of a 24 volts power rail instead of the 12V used at 35 watts and generally available within North American cars.

For equipment operating in a full duplex mode, duplexer filters in series with the PA are required to suppress transmitter wideband noise. The use of conventional helical or cavity resonators requires



Typical Block Diagram - AMPS Compatible Mobile Terminal, NBFM(12)

FIGURE 6

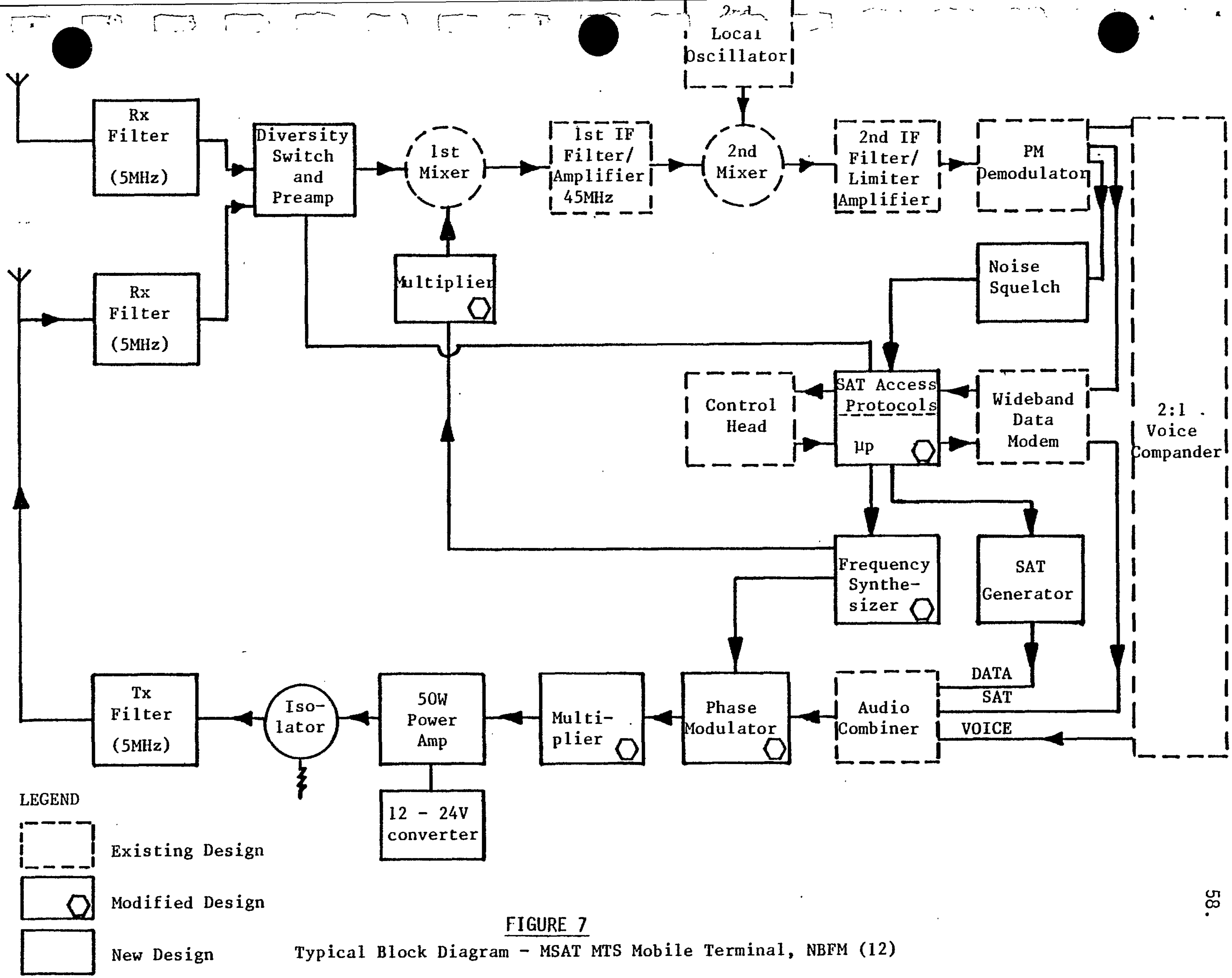


FIGURE 7

Typical Block Diagram - MSAT MTS Mobile Terminal, NBFM (12)

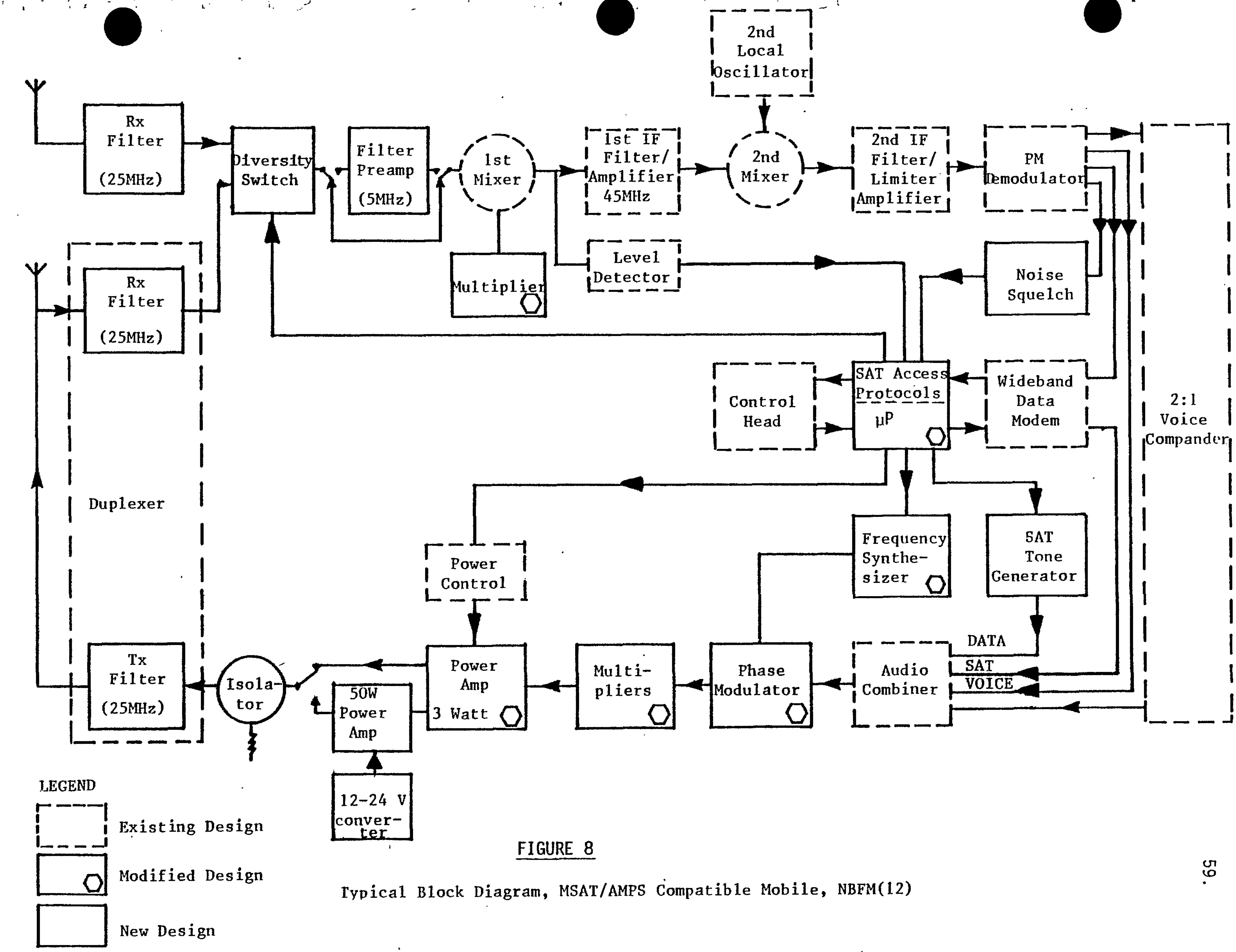
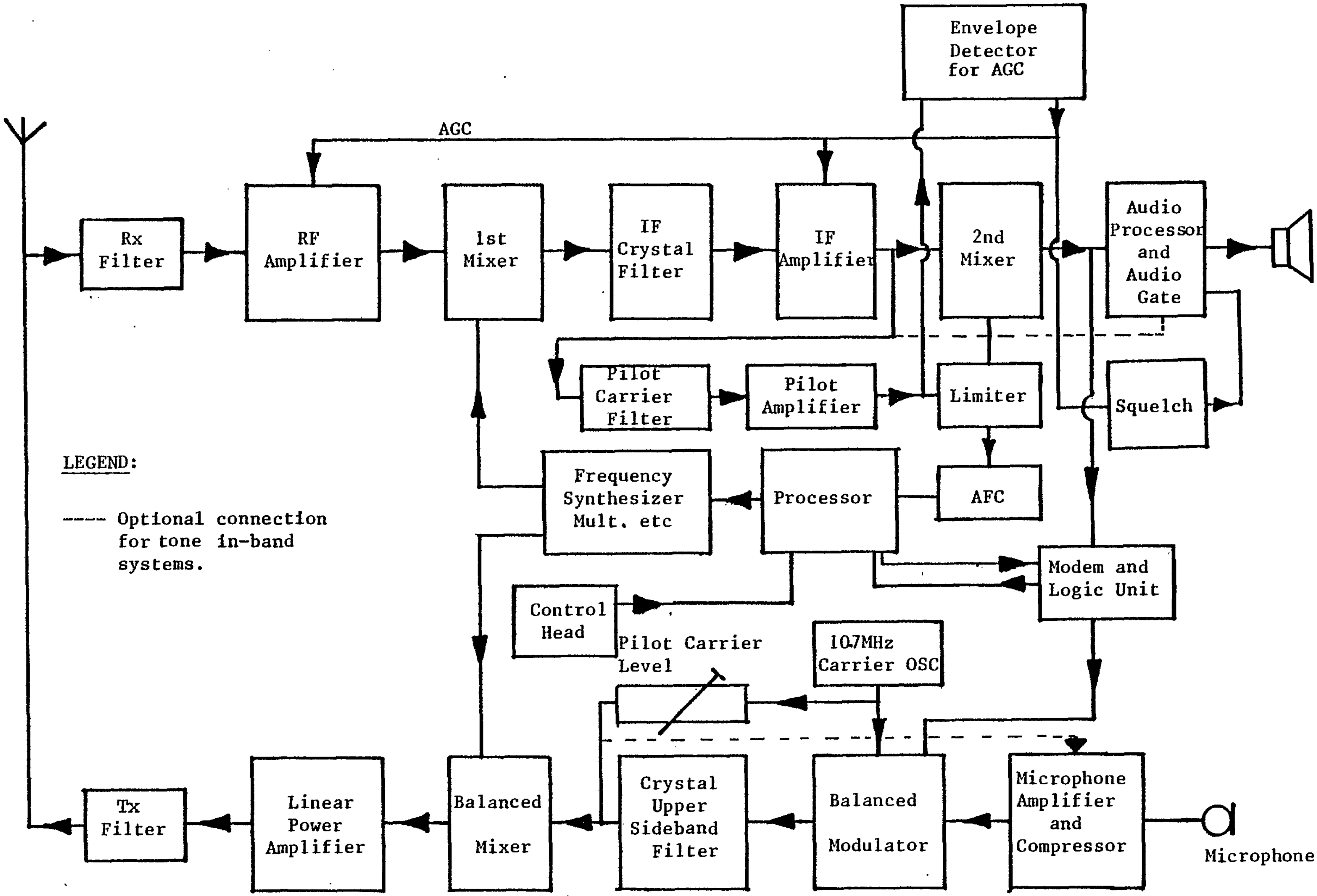


FIGURE 8

Typical Block Diagram, MSAT/AMPS Compatible Mobile, NBFM(12)



Typical Block Diagram - Pilot Carrier ACSB Transceiver

FIGURE 9

up to ten poles to obtain the 20 MHz bandwidth at 45 MHz transmit/receive separation planned for most cellular applications. It is difficult to maintain precise alignment within these filter so that resulting insertion losses of up to 3 dB should be anticipated which requires actual power amplifier outputs of 100 watts for 50 watts at the antenna terminal.

In many cellular type mobile terminals difficulties in achieving sufficient duplexer isolation, necessary to prevent receiver desensitization, results in a limitation of transmitter output power to only three watts.

It is reported (Ref. 5 and 6) that recently developed dielectric filters, capable of operation at input powers of 30 watts, can maintain insertion losses as low as 1.2 dB over a 24 MHz bandwidth. If these filters can be operated at higher powers it is believed that they would permit the objective for a compatible terrestrial/satellite terminal to be achieved, however, a 24V power supply system would still be necessary.

b) ACSB

Further work is necessary to establish the acceptable intermod levels for the ACSB mode of modulation, for which the reported protection margin is only 5dB (Ref.3). It is considered however that class B or AB power amplifiers will be required if sideband splatter is to be reduced to the levels necessary to obtain channel separation of 5 KHz. Despite lower average power requirements, the peak power of ACSB amplifiers is at a comparable level to that of equivalent performance FM amplifiers. Hence the amplifier should be rated at 50 watts peak and, because of the linearity, is almost certain to need a 24V power rail. Using conventional techniques low amplifer efficiency will require large heat sinks, however the development of polar-loop amplifiers (Ref.4) gives promise of high linearity at a high efficiency.

At this time linear amplifiers operating at 800 MHz are not generally available. Some divergence of opinion exists between manufacturers but the concensus suggest that, given sufficient volume, the cost of ACSB amplifiers would be within +20 percent of the cost of equivalent peak power FM power amplifiers.

8.2 RECEIVER SENSITIVITY

For commercially available terminals, receiver sensitivity is quoted in terms of the input level for 20 dB quieting; a typical figure being 0.5 microvolts. This is equivalent to a noise figure of 9 dB. Improvements through the use of a GaAS FET RF pre-amplifier, could result in improvement to typically 2.2 dB but produces insignificant improvement in the coverage within terrestrial systems. This modification is therefore unlikely to be developed for terrestrial application and is only likely to be introduced for satellite applications.
Highly selective RF filters with insertion losses of 1 to 2 dB, as required for suppression of high level interfering signals and 6 dB noise figure mixers, make any further improvements unlikely.

8.3 BANDWIDTH

For MRS operation the bandwidth of 5 MHz is well within the capability of current equipment particularly if operating in a half duplex mode.

For MTS operation however, the potential requirements of 25 MHz will be difficult to achieve simultaneously with the requirements for power output, receiver noise figure and dynamic range. (See Figure 10)

Almost all 800 MHz equipment is designed for half duplex or full duplex operations with a transmit/receive frequency spacing of 45 MHz. Bandwidths of up to 20 MHz for both transmit and receive are available through the use of 10-pole helical resonators.

Further increases in bandwidth using these present techniques are expected to be expensive. Estimates from one supplier indicate an additional user price of $93 Canadian for an increase of bandwidth from 20 to 30 MHz for operation at low power levels and receiver sensitivities appropriate to terrestrial systems. However at a 30 MHz bandwidth it is doubtful whether the power output and noise figure objective for MSAT could be achieved. It is reported (Ref.5 and 6) that dielectric type duplexer filters provide a 24 MHz bandwidth with high isolation and minimum insertion loss. Extension to meet the 25 MHz objective should be realizable using these techniques with only a small cost penalty provided that the 25 MHz filter becomes the standard design.

8.4 FREQUENCY SYNTHESIZERS

For the most part frequency synthesizers developed for the professional land mobile service are high quality single loop digital synthesizers. The design is driven by the need for high spectral purity to satisfy the overall mobile terminal objectives for adjacent channel selectivity and transmitter wideband noise output.

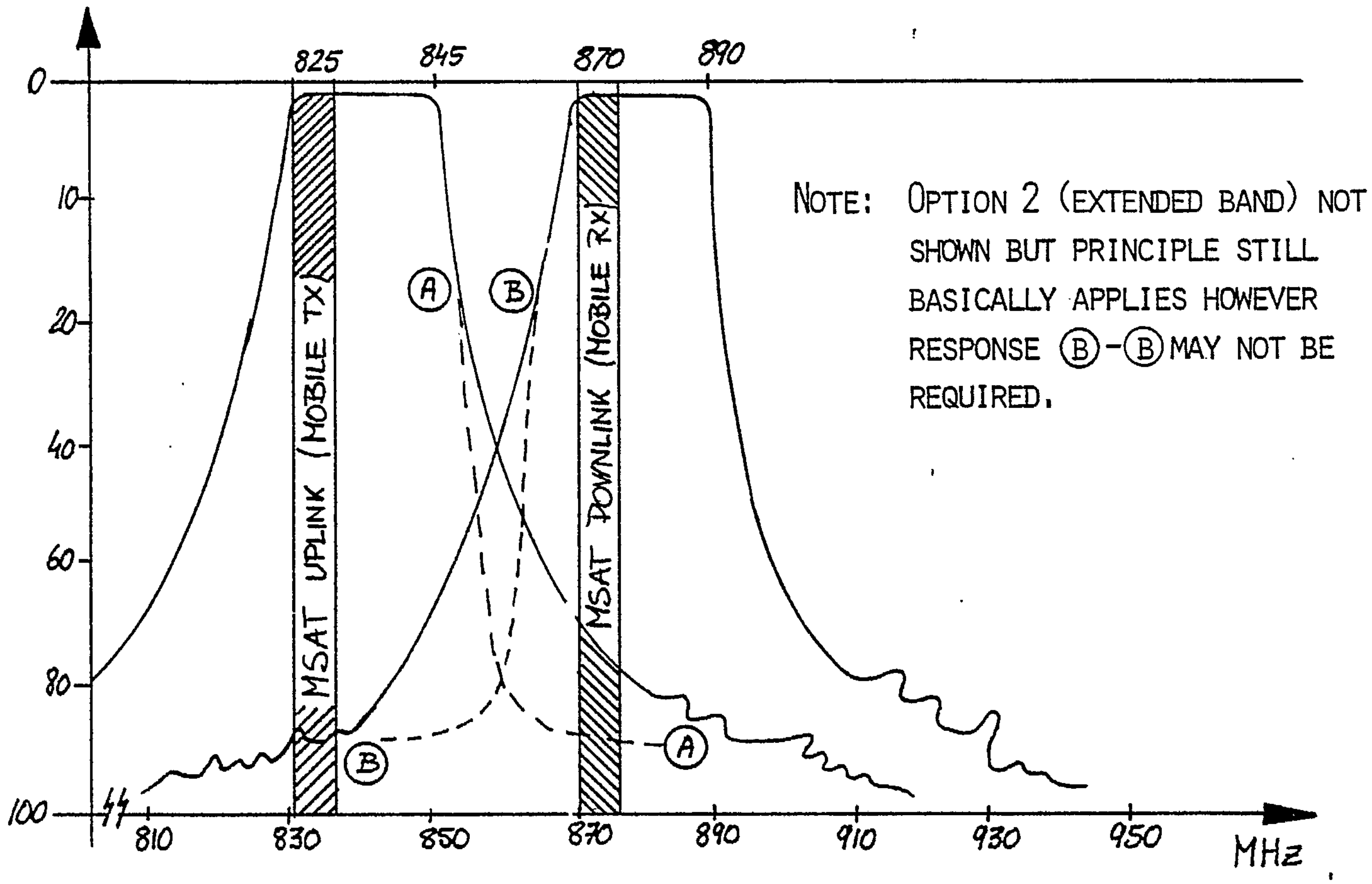


FIGURE 10. DUPLEXER FILTER REQUIREMENTS

For FM application step size is either 30 or 25 KHz. For ACSB modes 5 Khz and frequently 1 KHz step sizes are available.

For use in a compatible MSAT/terrestrial radio or a full duplex satellite only radio, a similar quality synthesizer is required. For use in a half duplex satellite only service however, the small dynamic range of signals allows the use of a lower quality synthesizer similar to those used in citizen band type radios. In many cases these provide small tuning increments which would allow the use of digital frequency off-setting to compensate for errors in the reference oscillator.

8.5 FREQUENCY STABILITY

The frequency stability of most high UHF band equipment is quoted at +/-2.5 ppm over an operating temperature range of -30 to 70 degrees C. This is adequate for NBFM but requires improvement to the order of +/-0.5 ppm for SSB or LPC application in order to prevent sideband spillover into adjacent channels. For SSB and possibly LPC further frequency error compensation is necessary to reduce overall error to less than about +/-20 Hz i.e, 0.04 ppm. Although proportional control ovened oscillators are capable of achieving a stability of 0.04 ppm, cost and power consumption are high. A possible alternative that could be cost-effective in an satellite only application, for which high spectral purity frequency synthesizers are not required, is that of digital frequency compensation within a small step size synthesizer. (See 8.4)

8.6 SIGNALLING AND SIGNALLING PROTOCOLS

Terrestrial systems currently available employ many non-compatible signalling techniques. For the MTS it is believed that the standard developed for cellular systems, and now incorporated as an EIA standard, will become universely adopted in North America. Terminals designed to meet the EIA standard are highly developed and incorporate a number of functions such as error detection, coding and bit synchronization in special purpose VLSI chips rather than in soft or firmware based general purposes processors.

a) MTS

In its present form the EIA standard is not directly compatible with the satellite MTS application although the elements requiring change, see 6.1.5 a), are implemented in software/firmware rather than customized chips. This leads to the possibility of minor software modifications permitting selectable modes of operation for use in either a terrestrial AMPS or the satellite component of an integrated system.

b) MRS

Signalling in the dispatch type services for the most part has been developed for use in systems wherein there are only a few trunked channels. In general they utilize signalling plus voice on all channels rather than dedicated signalling channels.

Due to the need to separate signalling from voice, signalling is frequently constrained to a small sub-audio frequency band. The data rates are consequently low and unsuitable for the MSAT system.

On the other hand the signalling developed for MTS cellular systems utilize high data rates, error detection, synchronization and multiple dedicated channels, the major features required for signalling to mobile radio users in the MSAT system. Implementation by means of of microprocessors facilitates recoding to incorporate alternative protocols such as slotted ALOHA (discussed in 6.1.5 b)).

8.7 ACSB

With the exception of the aircraft units manufactured by E.F. Johnson for the new airphone service neither SSB and ACSB mobile terminals are currently available in the high UHF band. Commercial products are available in the VHF band and tests have been reported at 450 MHz (Ref.7).

In terrestrial applications it has been found that fast and deep fading imposes severe requirements on the performance of AFC and AGC circuits. These are expected to be more severe at 800 MHz. Shadowing of the weak signals from satellites causes chopping and can be expected to impose similar severe requirements on both AFC and AGC.

The 800 MHz band units used in the airphone service have been developed for use between aircraft and fixed base stations. As a result clear a line-of-sight propagation path is enjoyed most of the time. This minimizes fading and chopping and eases the design of AGC circuits. In addition use is made of high stability frequency sources, external to the radio, to achieve a high frequency stability with a frequency error of typically only +/-80 Hz. The AFC circuitry is primarily therefore required to track and correct doppler frequency shifts, a maximum of +/-755 Hz at 600 M.P.H. However for the most part the doppler shifts change slowly and may be easily tracked and compensated.

The airphone equipment operates from the 28 Volt D.C. supplies available in most aircraft. Although 12 to 28 volts convertors could be used to adapt airphone units for mobile application there would be a penalty in cost, size and reliability.

From a consideration of the above points it is not considered that the airphone unit would be readily adaptable for use in a land mobile type of service.

The speech processing circuits associated with ACSB are still subject to optimization over real rather than simulated conditions. The effects of impulse noise from automobiles do not appear as yet to have been considered and although generally expected to be minimal at 800 MHz, cannot be neglected. Until such time as testing and optimization is completed, discrete component voice processors only will be available. Ultimately these circuits are expected to be suitable for single chip implementation. Thus the resulting cost should be comparable to that of the 2:1 speech compandors used in cellular type systems.

The use of heterodyne frequency conversion and linear amplifiers in both transmit and receive paths, as required for ACSB, permits many elements of the terminal to also be used for an FM mode of modulation. This would permit the spectrum and power efficiency of ACSB to be used over the satellite path, whilst NBFM could be used when in urban areas served by terrestrial cellular systems.

This is potentially useful for extension of the mobile telephone service Via satellite. However the Commercial Viability Study (Ref.1) concluded that this mode of operation would not be necessary to serve the projected traffic until the year 2001 when using a spacecraft based upon the LSAT bus.

8.8 LPC/RELP

Development of LPC10 and similar digital speech algorithms has been heavily oriented to military rather than commercial systems. Commercial products using the LPC10 algorithms are available but at this time the cost of $10,000 is too expensive for inclusion in a commercial land mobile communications system.

The development of special chip sets for purposes of digital speech processing is currently being financed by U.S. military sources. Products based upon these devices are expected to result in cost reductions to the order of $150 to $250 at the OEM level.

The development of more sophisticated algorithms such as RELP is still in a very early phase, most work being performed using mainframe computer emulations. Various reports, see bibliography, indicate a complexity at the hardware level of the order of 2:1 compared with LPC10 processors.

The availability of RELP hardware for mobile applications will depend to a great extent upon the results of extensive user acceptance testing of the various processing algorithms. Favourable reaction would likely result in rapid commercial development whereas a limited acceptance will likely result in development only for essential military or high security applications.

Using either direct FSK or subcarrier modulation techniques, many existing NBFM mobile terminals could, with only minor modification, be used in conjunction with LPC or RELP. Optimum efficiency however would not be obtained except by reduction of channel bandwidth and hence an increase in frequency stability.

For optimum performance within the reduced bandwidth either differential phase shift or minimum frequency shift keying is expected to be employed. In either case more complex modulators and demodulators are required, probably in conjunction with pilot tones, for AFC purposes. The same modulators and demodulators would also be used for purposes of signalling.

The power levels required for transmission via satellite using LPC are compatible with the power levels used for terrestrial systems using NBFM. The possibility of providing dual modes for satellite and terrestrial applications are therefore worth further consideration.

9.0 TERMINAL COST ANALYSIS

9.1 TERMINAL CONFIGURATIONS

The primary terminal configurations of interest, together with their potential service application, are shown in Table 10.

	TERRESTRIAL	SATELLITE
NBFM(S)	N/A	MTS
NBFM(T/S)	MTS	MTS
ACSB(S)	N/A	MRS/MTS
ACSB(T/S)	MRS	MRS/MTS
ACSB(S)/NBFM(T)	MRS/MTS	MRS/MTS
LPC(S)	N/A	MRS/MTS*
LPC(T/S)	MRS	MRS/MTS*
LPC(S)/NBFM(T)	MRS/MTS	MRS/MTS*

Table 10. Terminal Configurations and Applications

* Sub toll quality voice only in MTS application.

(S) Terminal performance (power output, noise figure, bandwidth) optimized for satellite only service.

(T) Terminal performance optimized for terrestrial service.

(T/S) Terminal performance expanded to facilitate both Satellite and Terrestrial services.

9.2 PRESENTATION OF RESULTS

As a result of the impending decision by the FCC to licence cellular systems cost information for specific products and variants thereof is in many case treated by manufacturers as proprietary information. To protect this proprietary price information, the approach estimates the cost deltas with respect to a baseline equipment for which actual prices are submitted to Department of Communications under a separate cover. This is considered a valid approach for mobiles to be used in the demonstration phase.

In all cases, see Table 8, the baseline terminal is the AMPS compatible NBFM terminal. This terminal was chosen as it a mature design available from both North American and worldwide suppliers, represents the latest state-of-the-art and includes many features expected to be found in an MSAT terminal, for example:

- microprocessor control
- demand assigned multiple access
- dedicated paging and access channels
- wide RF bandwidth of 20 MHz
- full duplex capability
- high performance frequency synthesizer
- data modem
- voice compandor
- mobile identification.

With the exception of the Dyna Tac portable produced by Motorola, the AMPS compatible terminals currently available are constructed using largely discrete and off the shelf integrated component technologies. The next generation is expected to use many more custom design integrated circuits and is widely forecast to result is a price reduction to the order of $1250 U.S. in large quantities. Making allowances for small quantities, duties and exchange rates this translates to a unit quantity price of $2875 Canadian. This is used as the baseline price in the operational phase.

Quantity discounts for large users may be estimated through the use of the discount curve. (See Figure 11)

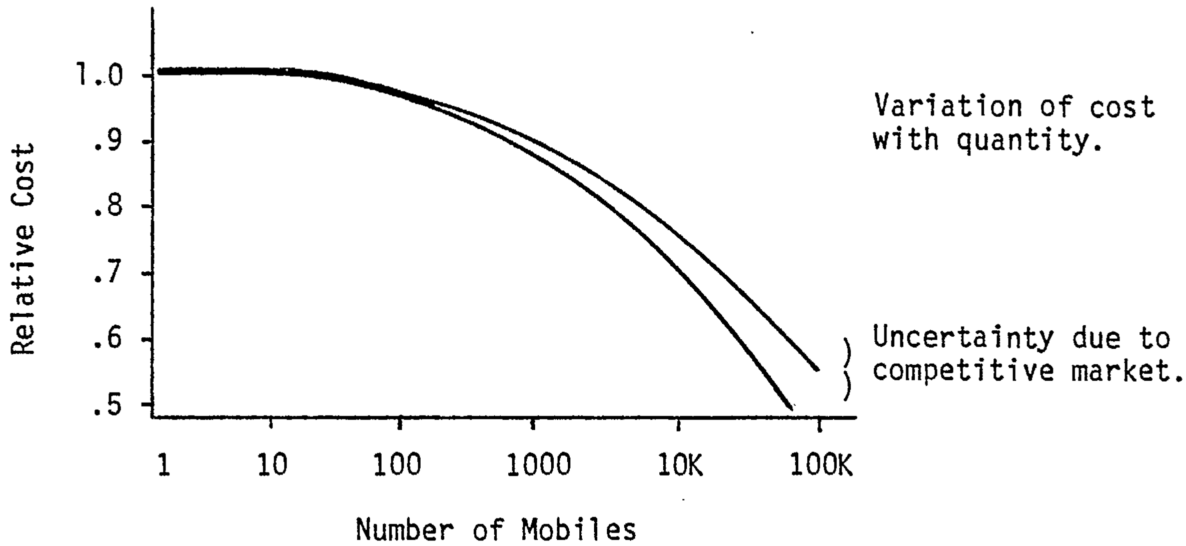


Figure 11. Discount Curves for Large Quantity Purchases.

The delta costs, see Tables 11 and 12, are the additional cost that must be added to the price of baseline terminal in order to obtain the unity quantity price. The cost given are based upon volume production and have been marked up to include manufacturing cost and overheads, profits, taxes, duties and currency exchange as appropriate.

For example, consider the cost of 10,000 ACSB terminals suitable for terrestrial and satellite operation during the life of the operational satellite.

Baseline cost operational phase	=	\$2875
From col. 4 of Table 12, Delta cost	=	<u>\$2265</u>
Total unit cost	=	\$5140

From Figure 11 Discount for 10,000 quantity 0.65.

$\therefore$ Quantity price = <u>\$3341</u>

9.3 COST DELTAS

DESCRIPTION OF CHANGE	NBFM (S)	NBFM (T/S)	ACSB (S)	ACSB (T/S)	ACSB/NBFM	LPC (S)	LPC (T/S)	LPC/NBFM
Power output (6 to 50 W)	625	750	N/A	N/A	N/A	N/A	N/A	N/A
Linear output (50 w peak)	N/A	N/A	750	1000	1000	N/A	N/A	N/A
Rx noise figure (9.0 to 2.2 dB)	150	250	150	250	250	150	250	250
RF bdwth reduction (20 to 5MHz)	(25)	N/A	(25)	N/A	N/A	(25)	N/A	N/A
RF bdwth increase (20 to 25MHz)	N/A	50	N/A	50	50	N/A	50	50
Half duplex	N/A	N/A	(100)	(100)	N/A	(100)	(100)	N/A
Freq. stability (2.5 to 0.5 ppm)	N/A	N/A	140	140	140	140	140	140
AFC/AGC	N/A	N/A	100	100	100	N/A	N/A	N/A
Signal protocols (satellite)	100	N/A	100	N/A	N/A	100	N/A	N/A
2.4 Kbps modem	N/A	N/A	1100	1100	1100	1100	1100	1100
4:1 Voice compandor	N/A	N/A	200	200	200	N/A	N/A	N/A
LPC voice processor	N/A	N/A	N/A	N/A	N/A	4500	4500	4500
TOTAL	850	1200	2415	2890	2990	5865	6090	6190

Table 11. Demonstration Phase, Delta Cost Breakdown.

N.B. For power outputs less than 35 watts, a 12:24 Volt convertor is not required. Prices will be 50 percent to 100 percent lower than shown in the first and second rows of Table 11.

DESCRIPTION	NBFM (S)	NBFM (T/S)	ACSB (S)	ACSB (T/S)	ACSB/NBFM	LPC (S)	LPC (T/S)	LPC/NBFM
Power output (6 to 50 W)	375	500	N/A	N/A	N/A	N/A	N/A	N/A
Linear output (50 W peak)	N/A	N/A	500	625	625	N/A	N/A	N/A
Rx noise figure (9.0 to 2.2 dB)	75	100	75	100	100	75	100	100
RF bdwth reduction (20 to 5MHz)	(25)	N/A	(25)	N/A	N/A	(25)	N/A	N/A
RF bdwth increase (20 to 25MHz)	N/A	50	N/A	50	50	N/A	50	50
Half duplex	N/A	N/A	(100)	(100)	N/A	(100)	(100)	N/A
Freq. stability (2.5 to 0.5 ppm)	N/A	N/A	50	50	50	50	50	50
AFC/AGC	N/A	N/A	25	25	25	N/A	25	N/A
Signal protocols (satellite)	20	N/A	20	N/A	N/A	20	N/A	N/A
Signal protocols (dual)	N/A	30	N/A	30	30	N/A	30	30
2.4 Kbps modem	N/A	N/A	350	350	350	350	350	350
4:1 Voice compandor	N/A	N/A	20	20	20	N/A	N/A	N/A
LPC voice processor	N/A	N/A	N/A	N/A	N/A	350	350	350
TOTAL	445	680	915	1150	1250	720	855	930

Table 12. Operational Phase, Delta Cost Breakdown.

10.0 CANADIAN MOBILE DEVELOPMENT

10.1 APPROACH

To determine the potential for designing and manufacturing an MSAT compatible mobile terminal within Canada, a questionaire was distributed to potentital Canadian companies. The questionnaire was followed up by telephone discussions with key personnel responsible for marketing and engineering development within the various companies.

10.2 RESULTS OF QUESTIONNAIRE

Detailed responses to the questionnaire were obtained from two companies. Since these results are considered proprietary they are submitted to the Department of Communications under separate cover. An overall summary of the questionnaire results and subsequent discussions is provided in Section 10.3.

10.3 ANALYSIS OF RESULTS

10.3.1 Interest

The Canadian mobile and related industries can be divided into three categories:

- Canadian manufacture based upon Canadian design and development;

- Partial Canadian assembly of products developed by offshore corporations;

- Canadian distribution of products manufactured offshore.

a) Canadian Manufacturers:

- Canadian Marconi Company
- International Systcoms
- Mitel Corporation (Special purpose components and ICs only)
- Glenayre Electronics Ltd. (Mobile Telephone Control Systems)

b) Canadian Assembly:

- Lenbrook Industries (E.F. Johnson)

- Canadian Motorola (Design development and manufacturing activities also performed in Canada but less then 25 percent of total output)

- Canadian General Electric

c) Canadian Distributors:

- International Aeradio (RCA)
- Spilsbury Communications
- Western Radio
- Pye Electronics
- R.F. Harris
- Racal Canada

Within these three groups, the Canadian companies indicating major interest were Canadian Marconi Company, Mitel, Glenayre, Lenbrook Industries Ltd. and Racal Canada.

In general the companies capturing a small percentage of the present FM market exhibit greatest interest. The potential for significant gains in market penetration through the use of new and possibly unique modulation formats or technology are cited as the major reasons for future participation in MSAT terminal development.

Those companies exhibiting little interest in the MSAT terminal development tend to be those enjoying a large share of the present FM market. The introduction of non-compatible MSAT terminals is seen as a dilution of the market rather than a potential market gain. Nevertheless, should a commercial MSAT enter into service these companies would be able to rapidly expand assembly and production facilities to produce a largely Canadian designed and manufactured terminal.

10.3.2 Canadian Content

During the production phase of MSAT terminals to be assembled in Canada, the Canadian content is projected to range between 25 and 87 percent for material and 80 to 92 percent for labour.

10.3.3 Production Staff

The production staff employed for production of MSAT terminals is projected to be 0.1 persons/mobile/month. Assuming a production rate of 20,000 units per year this would employ 166 persons on a continuous basis. All companies indicate the potential to expand to this production rate if require. It should be noted that total employment involving engineering, distribution and service staff could be expected to be in the order of 200 to 250 persons.

10.3.4 Non-Recurring Cost

From the separate reports on NBFM and LPC terminals prepared by Lenbrook Industries Ltd. and E-System Garland Division respectively, the non-recurring factory cost associated with development and tooling are estimated as shown in Table 13. To estimate potential contract values these figures should be increased by a factor of 2.2:1.

UNIT	MODIFICATION	COST
NBFM	50 watt power amplifier	$ 200K
(Full duplex MTS)	2.2dB preamp	55K
"	Duplexer	180K
"	MCLS software	500K
"	Miscellaneous	70K
	TOTAL	$1005K
ACSB	50 watt linear power A amplifier	$ 250K
(Half duplex MRS)	2.2dB preamp	55K
"	High stability oscillator	55K
"	MCLS software	500K
"	Convenience circuits	200K
"	Miscellaneous	140K
"	2.4 Kbit modem	50K
	TOTAL	$1250K
LPC	LPC encoder/decoder*	$ 100K
(Half duplex MRS)	2.2dB preamp	55K
"	High stability oscillator	55K
"	MCLS software	500K
"	2.4 Kbit modem	50K
"	Miscellaneous	100K
	TOTAL	$ 860K

Table 13. Non-recurring Cost of MSAT Terminal of Development Items.

* Assumes algorithms and chip set development cost absorbed by military development programs currently in progress.

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APPENDIX A

E-SYSTEMS, GARLAND DIVISION

PROJECTED AVAILABILITY AND COST
OF NARROWBAND DIGITAL VOICE EQUIPMENT
FOR USE IN MOBILE SATELLITE TERMINALS

PREPARED BY

E-SYSTEMS, GARLAND DIVISION

TEXAS

12 FEBRUARY 1982

NOTE

Prices quoted in this Annex are in 1981 U.S. dollars and represent the price to the original equipment manufacturer (OEM). Added value for mobile integration, factory overheads, marketing, profits, exchange rates and duties are applicable. These factors have been considered in this report and are included in the cost deltas shown in Tables 11 and 12.

PROJECTED AVAILABILITY AND COST
OF NARROWBAND DIGITAL VOICE EQUIPMENT
FOR USE IN MOBILE SATELLITE TERMINALS

1.0 INTRODUCTION

This paper addresses the feasibility of incorporating digital voice in the form of Linear Predictive Coding in the MSAT mobile terminals along with a suitable modem and Demand Assignment Multiple Access functions.

The first part of this paper describes the functional configuration of the terminal and the modulation techniques to be used. Following is a discussion of currently available hardware and costs of the component hardware units.

Next, current and anticipated developments through 1992 are considered. Based on these developments, estimates are made of possible unit sizes and costs for both the 1986 and 1992 time frames. All estimated prices are in 1981 U.S. dollars.

2.0 FUNCTIONAL DESCRIPTION

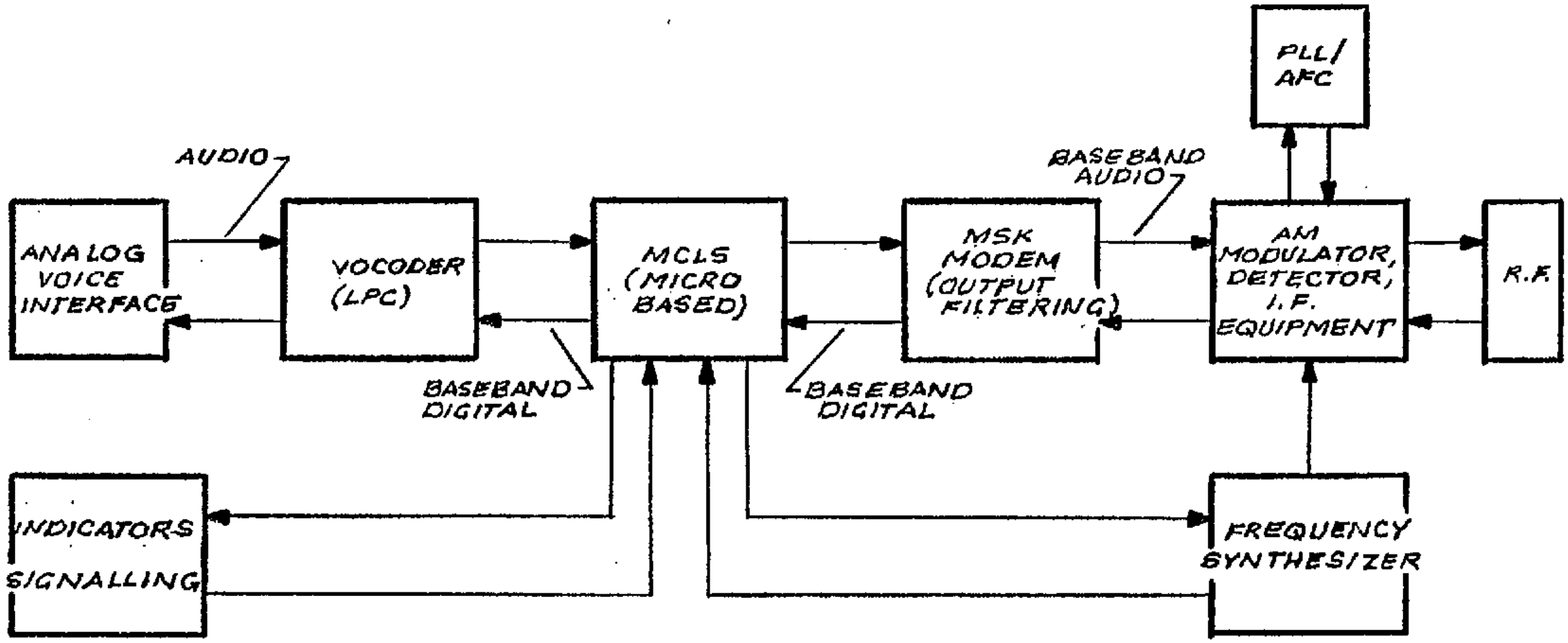
2.1 BASIC OPERATION

The expected terminal configuration is shown in block diagram form in Figure 1. The LPC Vocoder accepts audio from a handset and outputs a baseband digital signal at 2400 bps. This signal is fed to a microprocessor based Microcomputer Controlled Logic System. The MCLS handles the DAMA protocol functions and channel selection and switches in the LPC output at the appropriate time. The output of the MCLS is applied to an MSK modem the output of which is a baseband audio signal. This signal is used to amplitude modulate the R.F. carrier. The received signal is envelope detected and the resulting audio signal applied to the MSK modem. The output of the modem is a baseband digital signal which is fed to the MCLS. The MCLS examines this signal and routes it to the vocoder at the proper time. The output of the vocoder is an analog voice signal which is sent to the handset.

2.2 THE MSK MODEM

MSK (Minimal Shift Keying) is the name applied to a particular case of continuous phase frequency shift modulation. In particular, it is FSK with modulation index 0.5 and continuous phase transitions. Its advantage relative to more common hard-keyed PSK is the rapid decay of its spectral sidelobes with frequency. The MSK spectrum decays in inverse proportion to the fourth power of frequency as opposed to the second power of frequency for hard-keyed PSK. A related advantage claimed for MSK is minimal sidelobe regeneration when the signal is processed by a saturating amplifier - a characteristic which can be used to advantage in the demodulation process.

An MSK signal can be considered either as an FSK signal with minimal shift or as a binary PSK signal. When looked upon as PSK the signal can be considered as two carriers of the same frequency in phase quadrature.



PLL/ AFC
AUDIO
BASEBAND AUDIO
ANALOG VOICE INTERFACE
VOCODER (LPC)
MCLS (MICRO BASED)
MSK MODEM (OUTPUT FILTERING)
AM MODULATOR, DETECTOR, I.F. EQUIPMENT
R.F.
BASEBAND DIGITAL
BASEBAND DIGITAL
INDICATORS
SIGNALLING
FREQUENCY SYNTHESIZER

One is full wave modulated by a sine function whose frequency is one quarter of the bit rate and the other is modulated by the cosine of the same frequency. The information is conveyed by means of 0° of 180° phase changes between two successively transmitted elements. This type of modulation is also known as offset QPSK. When the two modulated carriers are added the end result has the appearance of an FSK signal where a '1' is represented by the higher of two frequencies and a '0' by the lower and the two tones are separated by one-half the bit rate. This is illustrated in Figure 2.

This characteristic of MSK can be exploited to considerably reduce the complexity of the modem as long as modulation and demodulation are accomplished at base band rather than at I.F. The FSK nature of MSK can be used to simplify the generation of the signal for transmission while the PSK characteristics can be used to reduce the complexity of demodulation to an almost trivial process.

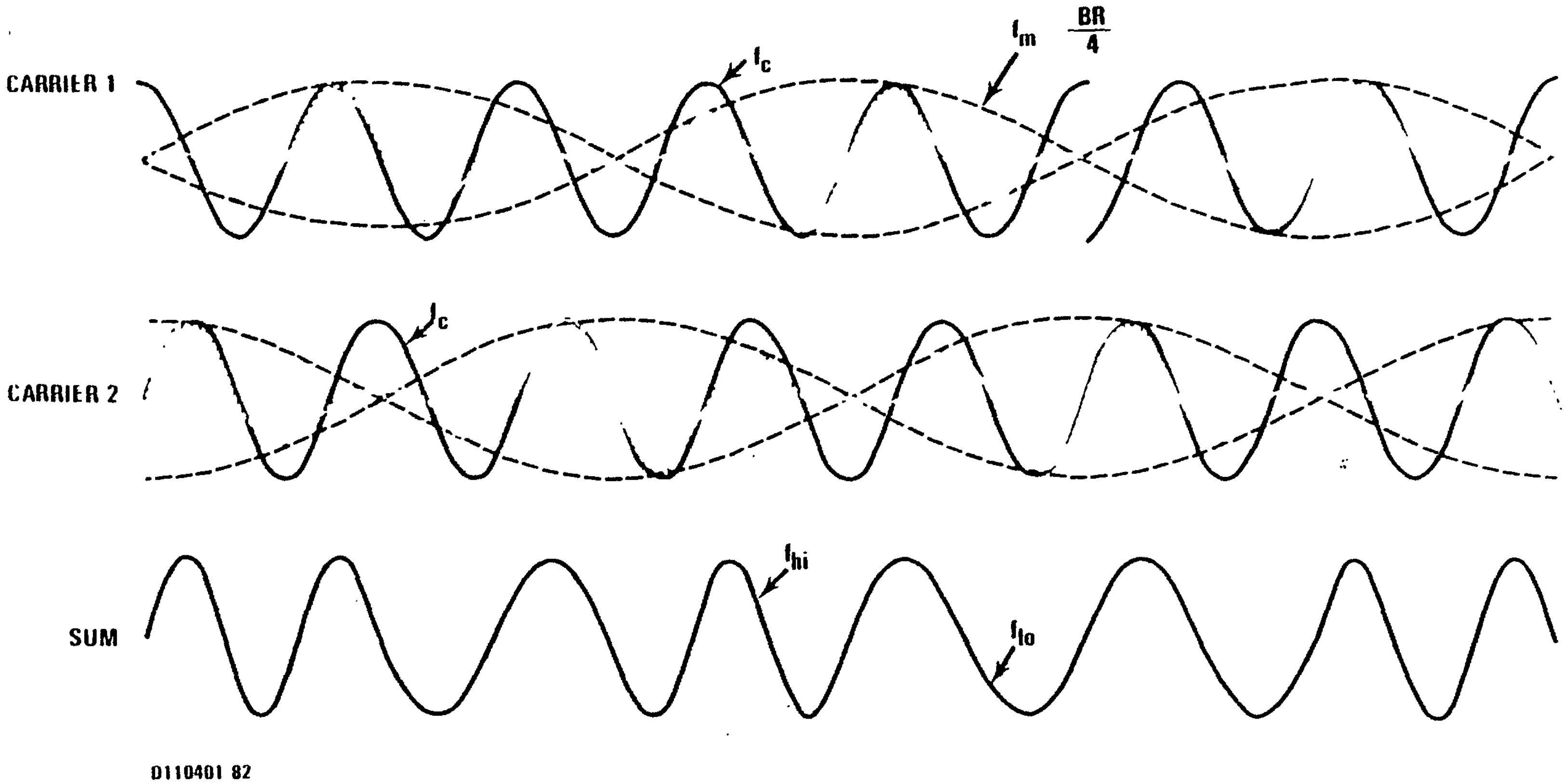


FIGURE 2

3.0 EXISTING HARDWARE AND COSTS

3.1 LPC

Commercial voice digitizers are currently available from several manufacturers including E-Systems, TSP and Codex but they are all quite large and expensive. In quantities of 100, E-Systems units will cost about $10.5K and TSP and Codex units can be expected to cost about $13K.

3.2 MSK MODEM

No commercial MSK modems are known to exist. An MSK modem for military satellite use has been developed by Linkabit but is not currently in production. This modem, unfortunately, was designed to interface with a radio at the 70 MHz i.f. level and can be expected to cost about $25K/ unit when in production.

It is more than likely then that a baseband MSK modem will have to be developed for use with the test satellite.

3.2 MCLS

Although the microprocessors and supporting chip sets are available today the total MCLS will have to be developed for this particular application.

4.0 PROJECTIONS FOR 1986

4.1 LPC

There are two known ongoing development efforts to produce LPC chip sets using VLSI. One is being conducted by NEC but nothing has been officially announced. It has been rumored that the NEC LPC set will consist of 4 chips which will probably require some non-LSI supporting circuitry.

Motorola is currently under contract to the U.S. Navy to develop an LPC chip set but development is far from complete. The most complex chip-or-chips, the analyzer, is not expected to be complete until 1985 or 1986.

If either one of these chip sets is available by 1985 or 1986 an LPC unit can probably be developed that will fit on one 6 in. by 10 in. card. Unit development and packaging costs can be expected to range from $50K to $80K. In early production of the LPC chip sets, due to small production quantities and low yields the cost of the chip sets alone can be expected to be quite high - $1000 to $1500. Consequently, in 1986 an LPC unit can be expected to cost between $2000 and $2500 in 100 quantity.

Another interesting possibility which is probably achievable by 1986 is the development of an LPC unit using currently or then available signal processing chips such as the NEC PD7720. MIT has designed a channel vocoder using this type of circuitry that will fit on a 7 in. by 7 in. card. By 1986 an LPC vocoder could probably be designed to fit on a 6 in. x 10 in. card that would sell for about $1000 per unit in quantities of 100.

4.2 MSK MODEM

Because of low general interest in MSK it is unlikely that an "off the shelf" modem will be available in 1986. An MSK modem can be designed using currently available integrated circuits that will fit on one 6 in. x 10 in. card. Development and packaging costs can be expected to be about $20K to $30K. Price of the units in quantities of 100 should be about $800.

4.3 MCLS

Like the MSK modem it must be assumed that the MCLS will be custom designed for this particular application. The MCLS can be designed using existing circuits that can be packaged on a 5 in. x 7 in. card. Development and packaging costs including software should be about $50K. In production quantities of 100, the sale price of an MCLS should be about $1000.

APPENDIX B

LENBROOK INDUSTRIES LTD.

DESIGN AND COST CONSIDERATIONS

FOR THE MODIFICATION OF

CELLULAR MOBILE TERMINALS FOR USE WITH MSAT IN THE NBFM MODE

PREPARED BY

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FOR

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DESIGN CONSIDERATIONS FOR MODIFICATION OF A CELLULAR MOBILE TERMINAL FOR USE WITH MSAT (NBFM)

1.0 INTRODUCTION

This paper describes design considerations to modify an existing narrow-band FM (NBFM) cellular mobile terminal for use with the proposed MSAT which may be used to estimate cost and risk impact for such modified equipment.

2.0 ASSUMPTIONS

a) MSAT channels are 30 KHz spaced NBFM.

b) Two frequency allocation options are assumed and considered. Present cellular allocations are shown in Fig. 1(a).

Option A) 20 MHz TX and 20 MHz RX with T/R separation of 45 MHz. MSAT allocations are a 5 MHz portion of this proposed cellular band. This is shown in Fig. 1(b) & (c).

Option B) 25 MHz TX and 25 MHz RX with T/R separation of 45 MHz. MSAT allocation is a 5 MHz band immediately adjacent to the proposed cellular bands. This is shown in Fig. 1(d) & (e).

c) It is assumed that an existing cellular mobile will be modified. Design and manufacture of a completely new mobile terminal is not considered. This assumption has been made because large portions of the 30 KHz NBFM cellular mobile can be common for both MSAT and cellular use thereby resulting in substantial saving. It is our opinion that design and manufacture of a completely new mobile terminal may also be undertaken but would not provide significant cost advantage over a combined unit if produced in reasonable quantities. If, however, a NBFM MSAT-only mobile terminal is required, it should be relatively easy to envision such a terminal from this paper, and to draw technical and economic conclusions.

d) It is assumed that the user will be provided with a switch on the control unit of the mobile terminal to choose either terrestrial cellular or MSAT mode of operation. In this way, the mobile terminal will internally be reconfigured for proper operation in either mode.

METRIC

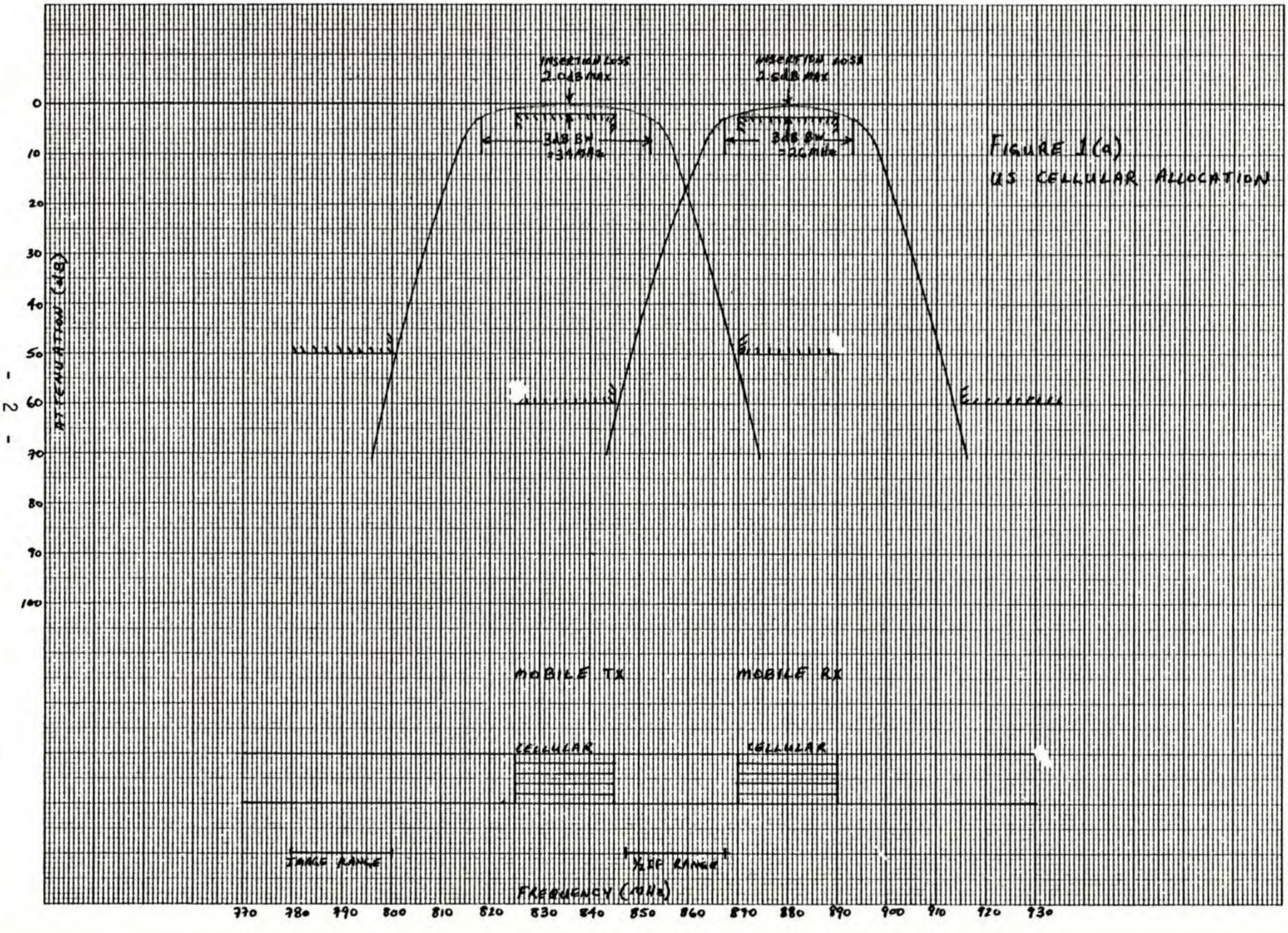

FIGURE 1(a)
US CELLULAR ALLOCATION

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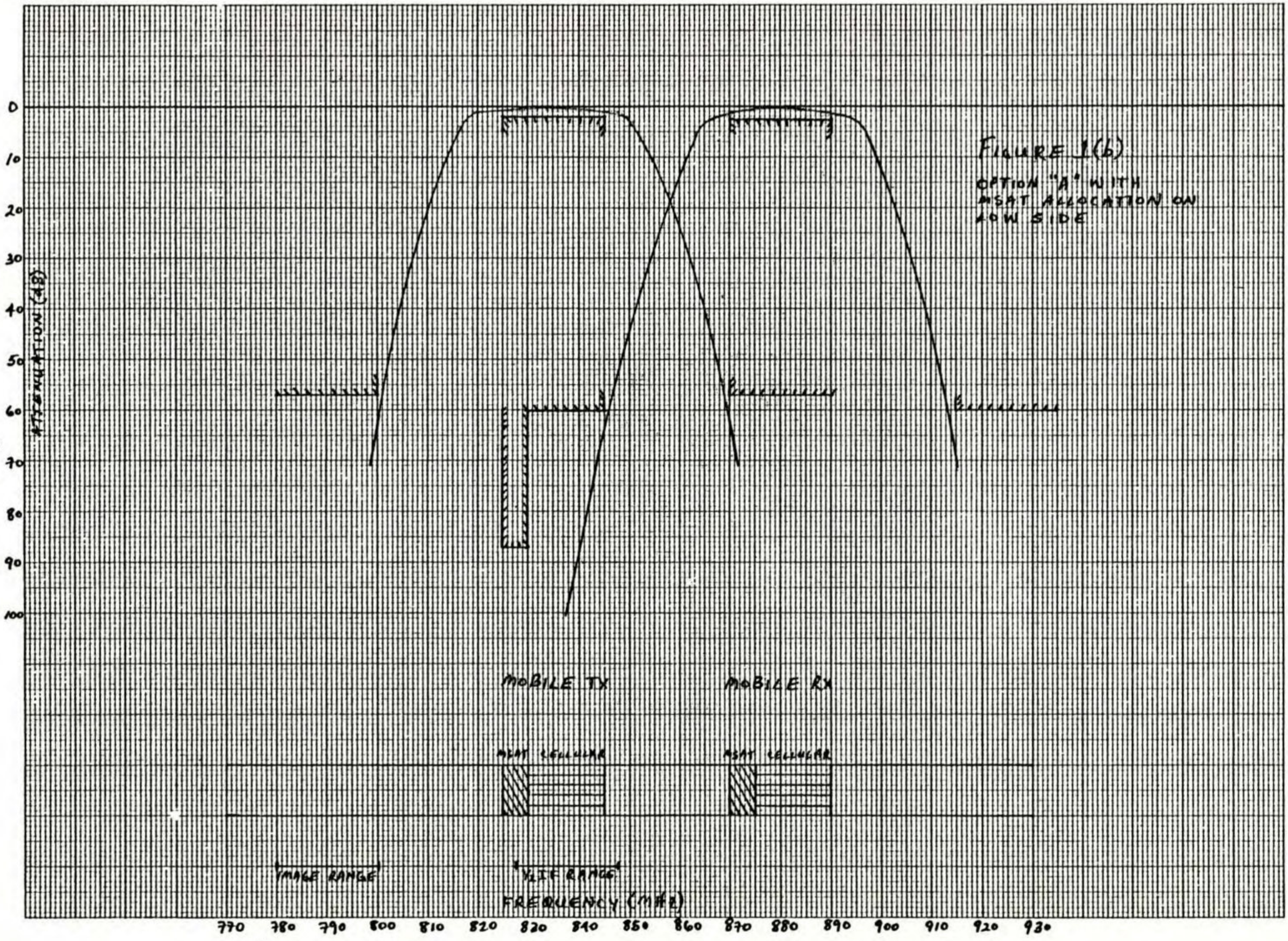

FIGURE 1(b)
OPTION "A" WITH
MSAT ALLOCATION ON
LOW SIDE
ATTENUATION (dB)
0
10
20
30
40
50
60
70
80
90
100
MOBILE TX
MOBILE RX
MSAT CELLULAR
MSAT CELLULAR
IMAGE RANGE
½ IF RANGE
FREQUENCY (MHz)
770
780
790
800
810
820
820
840
850
860
870
880
890
900
910
920
930

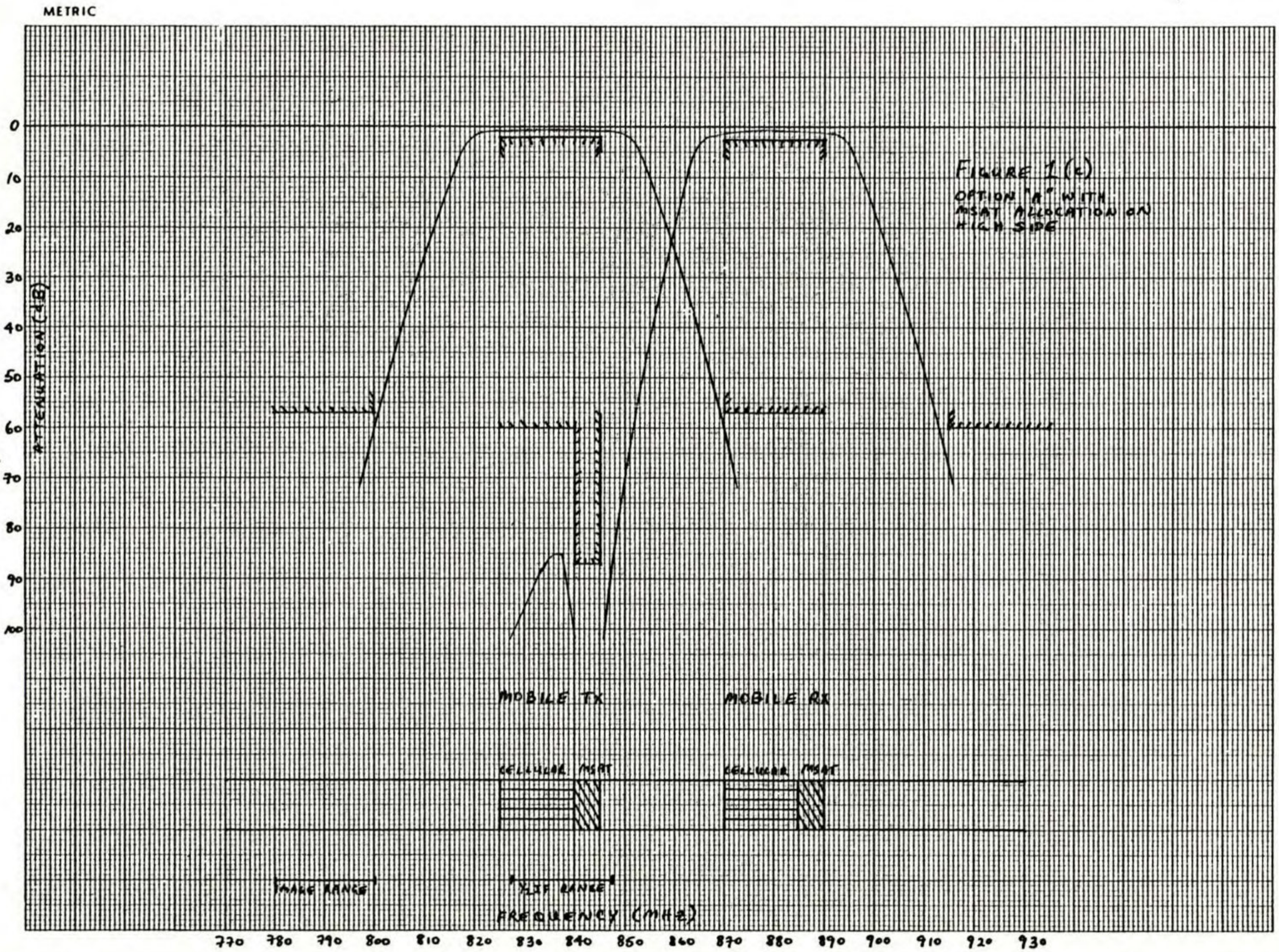
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FIGURE 1(c)
OPTION "A" WITH
MSAT ALLOCATION ON
HIGH SIDE
ATTENUATION (dB)
0
10
20
30
40
50
60
70
80
90
100
MOBILE TX
MOBILE RX
CELLULAR
MSAT
CELLULAR
MSAT
IMAGE RANGE
½ IF RANGE
FREQUENCY (MHz)
770
780
790
800
810
820
830
840
850
860
870
880
890
900
910
920
930

METRIC

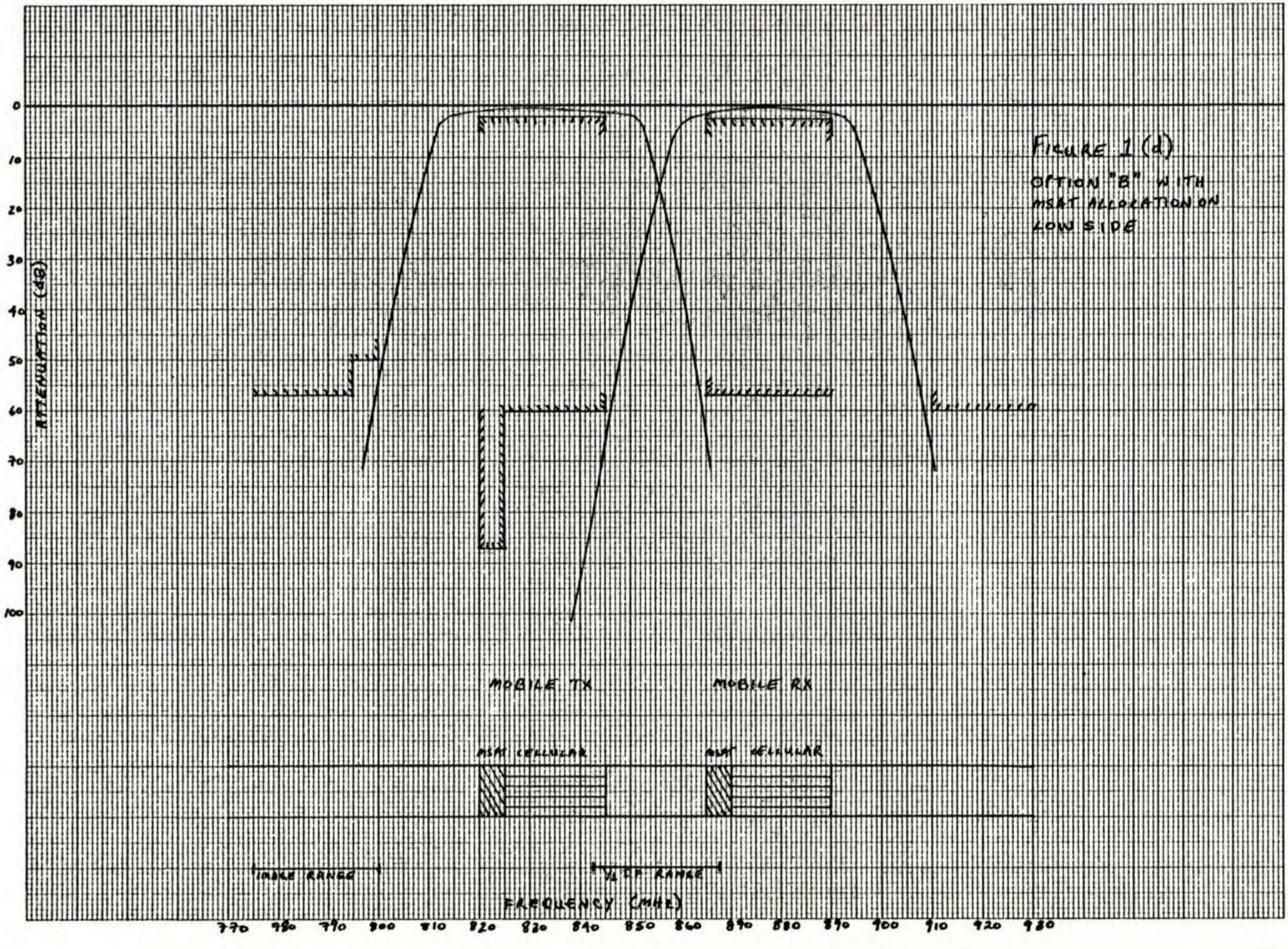

FIGURE 1 (d)
OPTION "B" WITH MSAT ALLOCATION ON LOW SIDE

METRIC

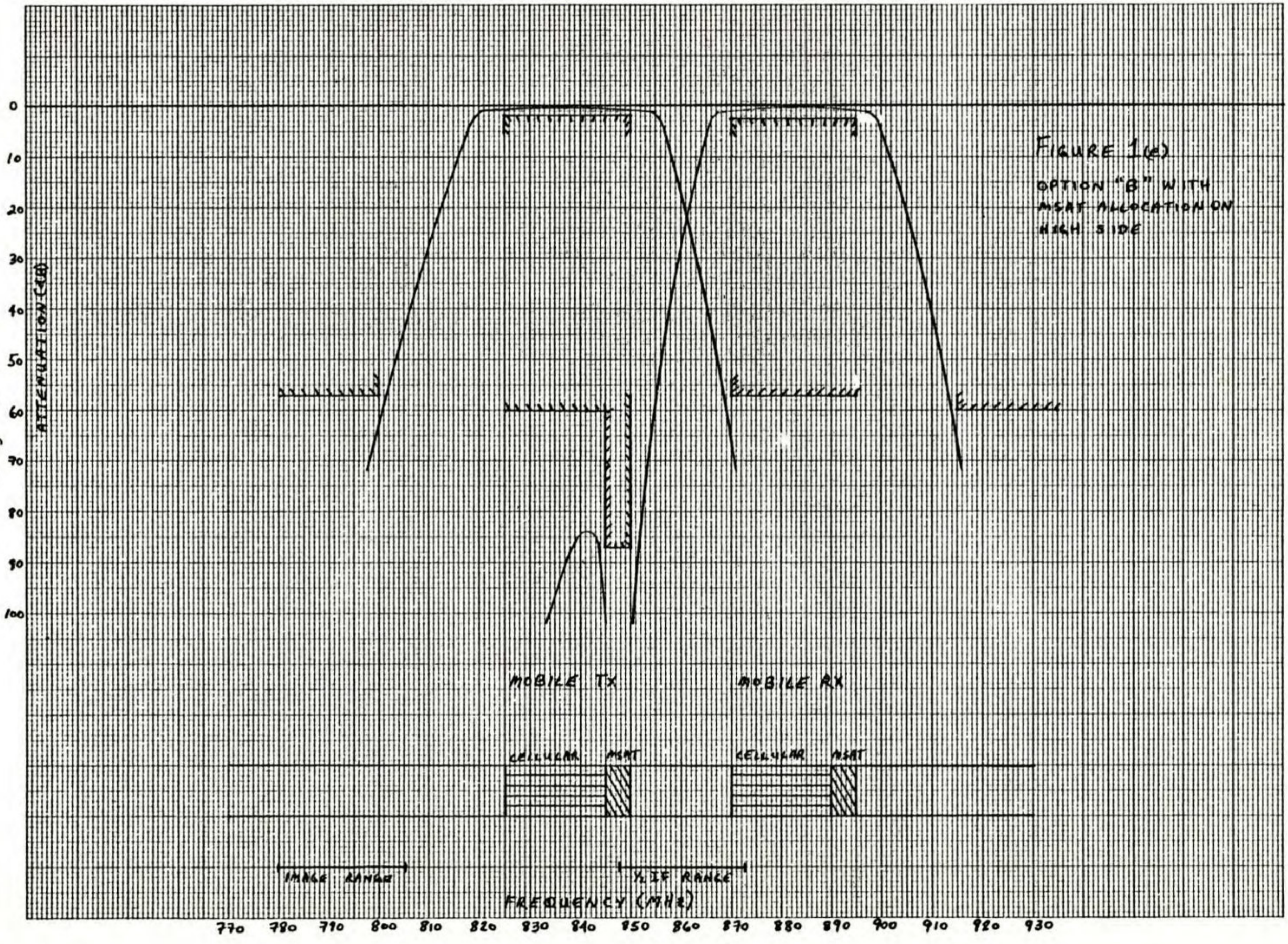

FIGURE 1(e)
OPTION "B" WITH MSAT ALLOCATION ON HIGH SIDE
ATTENUATION (dB)
0
10
20
30
40
50
60
70
80
90
100
MOBILE TX
MOBILE RX
CELLULAR
MSAT
CELLULAR
MSAT
IMAGE RANGE
½ IF RANGE
FREQUENCY (MHz)
770
780
790
800
810
820
830
840
850
860
870
880
890
900
910
920
930

3.0 DESCRIPTION OF BASELINE MOBILE TERMINAL

A baseline mobile terminal was selected on which to base design and cost considerations for integration of MSAT capability. The unit selected is a first generation AMPS type terrestrial cellular radio which was one of the three mobile terminals selected for the Chicago trial AMPS cellular system.

This radio is a NBFM transceiver with the following general characteristics:

FREQUENCY	825-845 MHz TX 870-890 MHz RX
T/R SEPARATION	45 MHz
POWER OUTPUT	12 WATTS CONTINUOUS WITH 0, -6, -12, -18dB STEPS
FULLY DUPLEXED	
DIVERSITY	ANTENNA SPACED PRE-DETECTION TYPE
FREQUENCY SYNTHESIZER REFERENCE TCXO	$\pm$2.5 ppm (-30^{o}C to +60^{o}C)
CHANNEL SPACING	30 KHz
MICROPROCESSOR CONTROL	AMPS PROTOCOL
RX SENSITIVITY (12dB SINAD)	0.35 uV (-116dbm)
TYPE OF MODULATION	NARROW-BAND FM
IF FREQUENCIES	45 MHz, 10.7 MHz

NOTE - The power output specification for future AMPS mobiles has been changed to 3 watts continous with eight 4dB power control steps (0, -4, -8, -12, -16, -20, -24, -28dB).

4.0 MODIFICATION CONSIDERATIONS

4.1 POWER AMPLIFIER - Optimum transmitter design for MSAT/cellular would entail a 60W PA with a wide range of power control. This range is determined by the lowest power required for terrestrial use (-28dB below 3W) and the high power level required for MSAT use (60W = +13dB above 3W). This makes the total range equal to 41dB.

Current RF transistor technology makes a PA with such wide range difficult to design and even more difficult to mass produce. Problems entail efficiency of large transistors at low drive levels and PA stability (due to shifts in the device parameters) over wide ranges of drive levels, temperatures and voltages.

One solution to this problem is to use the 3W output to drive high level stages only when in the satellite mode. The high level stages would be switched in the circuit when the mobile is in MSAT mode only. Switching could be accomplished using a relay or diode steering. It is expected that to achieve 13dB gain, a three-stage drive chain would be used. It is also suggested that consideration be given to using a semi-continuous duty cycle for the 60W output stages rather than a continuous duty cycle.

4.2 RECEIVER FRONT END AMPLIFIER

A similar diode-steering approach could be used to add a low-noise preamplifier to the receiver in the MSAT mode (see Fig. 3). It is important that this unit is switched out of the circuit when in the cellular mode because of degradation to intermodulation and RF overload characteristics if left in. In the terrestrial environment, such degradation is not acceptable.

Low-noise preamplifiers with 2.2dB NF and 20dB gain are commercially available at the present time.

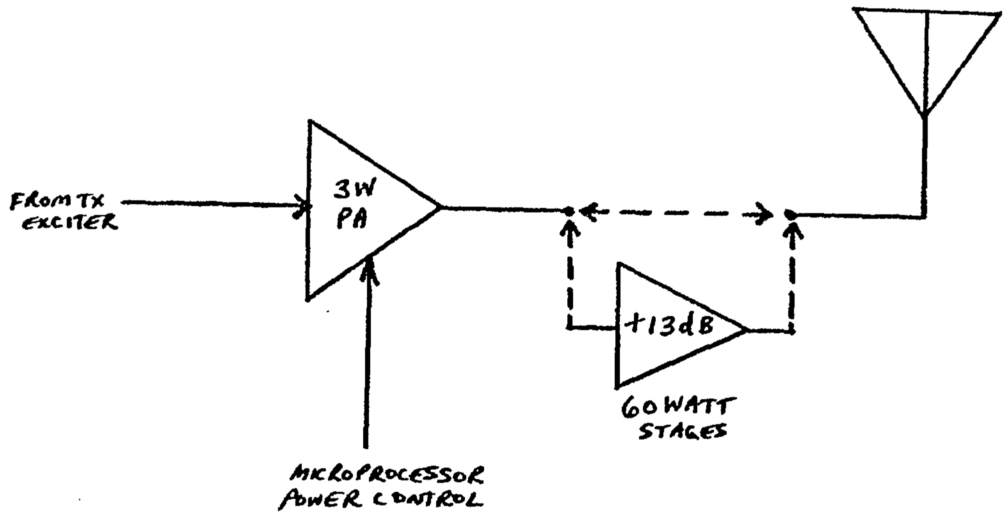

FIGURE 2 — POWER AMPLIFIER

With current advances being made in GASFET technology, an 800 MHz GASFET mixer may be available in the next 5 years with the required high sensitivity, low noise figure and wide dynamic range. Such a device would eliminate the need for a separate low-noise preamplifier.

4.3 DUPLEXER

The requirements for the baseband radio duplexer are shown in Fig.1(a). Note that this is based on a transmitter power level of 12W. The duplexer is actually two band-pass filters (BPF), one RX BPF and one TX BPF connected to the TX/RX antenna port. The other antenna port is used for receive only and has a second RX BPF connected to it (see Fig.3)

The two RX BPF's are identical and are implemented as 6-section helical resonator filters. These filters provide front-end selectivity for the receiver by rejecting unwanted spurious and image frequencies and attenuate the strong transmitter signals to prevent them from desensitizing the receiver.

The TX BPF is a 6-section coaxial interdigital filter. It attenuates unwanted spurious and harmonic signals produced by the transmitter and reduces the level of broadband transmitter noise (especially in the receive band). Low insertion loss is a particularly important requirement of this filter.

As can be seen in Fig.1(a), the ½IF range of frequencies (22.5 MHz below the RX frequencies) are close to the RX band because of the wide RX bandwidth. Option B aggravates this situation to some extent. The BPF's do not provide total protection to ½IF interference; however, the mixer device is capable of providing approximately 60-65dB of rejection. If better rejection is desired, only relatively complicated alternatives exist. One solution is to use a frequency agile filter to give added ½IF protection. Another alternative is to increase the IF frequency, which gives rise to changes in the synthesizer and the basic frequency architecture of the radio. This paper does not deal with these areas. It is not expected that increased ½IF rejection is necessary.

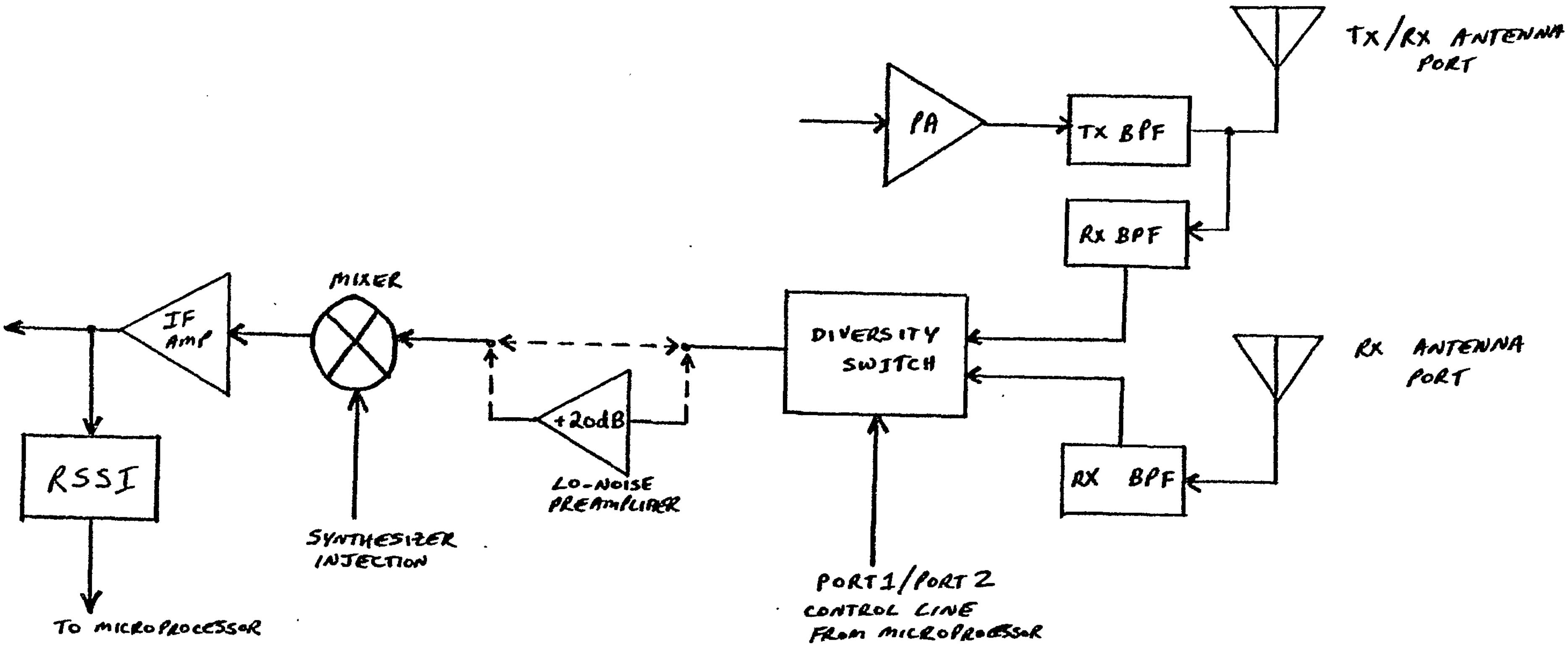

FIGURE 3 – RECEIVER

Assuming that the requirements of Fig.1(a) give adequate protection in the baseline terminal, we can generate the equivalent protection requirements for allocation options A and B with the further cases of the MSAT band allocations on the high or low side of the terrestrial channels. These requirements are shown in Fig.1(b)-(e).

Because of the increased power level (60W is 7dB above 12W), the transmitter BPF protection must be increased by 7dB to ensure that the broadband noise output remains the same (in the receiver passband especially). This added protection needs only to be added when in the MSAT mode, thus suggesting that extra filter sections should be switched in with the high power stages. These sections could be designed for 5 MHz bandwidth.

The RX BPF protection requirements are similar. Extra isolation is required only when in MSAT mode because of 20dB of extra receiver gain as well as 7dB extra transmitter gain. Again this would suggest switching extra filter sections in and out with the preamplifier. These sections would be in the form of a notch (suckout) covering the 5 MHz MSAT transmit band.

The most difficult filtering requirements are encountered in Fig.1(e). This is because of the increased nose bandwidth, narrowing of the inside protection band between RX and TX bands and the fact that the higher power MSAT transmit frequencies are closer to the receive band. It is our opinion that a maximum of 2 more sections per filter would be required to achieve these worst case requirements.

Large advances are being made in duplexer technology, including progress in smaller cavity design, as well as dielectric resonator technology which promises to significantly reduce cost. These advances are largely the result of the massive R and D expenditures being made for terrestrial cellular radios. Spinoffs would naturally accrue to MSAT mobile terminals as well.

4.4 DIVERSITY

Diversity switching is controlled by the microprocessor based on the output of the receive signal-strength indication (RSSI) circuit. The RSSI circuit is in turn driven by the IF signal level. It is expected that operation with lower RF signal levels in the MSAT mode would be taken care of already because of the gain of the low-noise preamplifier which would tend to maintain IF signal levels. To provide independent diversity thresholds (if necessary) would be a relatively minor design consideration. The diversity switching algorithm could also be changed since it is a software function.

4.5 SIGNAL CONVERSION

Mixer design should not be compromised. The low-noise preamplifier should present normal signal levels to the mixer and should have the gain required to compensate for the additional required sensitivity.

4.6 FREQUENCY SYNTHESIZER

The frequency range of the synthesizer is not expected to pose much difficulty. In the baseline terminal, the synthesizer operates at approximately 200 MHz with (X4) multipliers. Therefore the range would need to be increased from approximately $20 \div 4 = 5$ MHz to $25 \div 4 = 6.25$ MHz, an increase of 25%. Temperature stability is already determined by the synthesizer reference TCXO and this poses not additional cost penalty.

Channel switching time in the terrestrial mode is specified at 40 msec maximum because of the more demanding frequency agility required for cellular handoff. Therefore, the 200-300 msec requirements in the MSAT DAMA proposals are significantly more relaxed than the terrestrial requirements and pose no additional cost penalty.

4.7 IF

No change anticipated.

4.8 AF SECTION

Pre-emphasis and de-emphasis is provided already in the cellular mobile.

The slope is 6dB/pctave over the audio passband. It is assumed that this will be sufficient and that no modification is required. Companding (2:1) is also used in the baseline radio and may be disabled under logic control.

4.9 MICROPROCESSOR CONTROLLED LOGIC SUBSYSTEM (MCLS)

The baseline radio already contains an MCLS. This unit presently provides all of the requirements outlined for the AMPS protocol in the terrestrial environment. Signalling for MSAT is proposed at 10 kbps to be compatible with the present AMPS signalling rate of 10 kbps.

It can be reasonably assumed that the hardware will not change significantly and that changes will be software oriented. Corresponding memory expansion may be necessary. The bulk of the control circuitry is integrated with the main radio package and limited circuitry is put in the control head. It is expected that this will remain the preferred configuration because of the need for many control connections to the radio cicuitry (especially to the synthesizer) as well as the premium of space in the control head. However, as VLSI circuits for AMPS develop and miniaturization of other AMPS circuits develop, spinoffs will impact MSAT terminals also.

The MCLS software for the MSAT DAMA protocol would be significantly different from the AMPS protocol software. Call handoff, for example, is not required and the software required in the baseline terminal for this function is significant. Other factors are the satellite propogation delay time estimated at 532 msec plus processing times of up to 450 msec as well as other incompaitiblities between AMPS and MSAT DAMA protocols. This demands new software for the MSAT requirement.

Therefore, two partitioned software programs would be contained in program memory, one for the normal cellular mode of operation and the other for MSAT operation.

The user controlled mode switch would cause the processor to choose the proper software to be used in that particular mode. This software could be used to reconfigure the RF circuitry to the corresponding mode.

The software design for the baseline mobile terminal was a relatively large development, and it is expected that the new software required for the MSAT mode would approach the same proportions. Development time saved by using common portions of software for both modes is expected to be roughly offset by the additional time required to develop the necessary transitional software from one mode to the other.

It may be preferred that the mode control is not a user function, but that the terminal switches to MSAT mode automatically (software driven) whenever out-of-range conditions occur on terrestrial channels (and vice-versa). This is possible but poses additional software development complexities. Indicators would also be required to notify the user of the mode in use.

The speed required of the processing circuitry is not expected to be altered by the MSAT protocol because of the longer delay times, lack of handoff requirements, and smaller amounts of data transmitted in the MSAT DAMA system than in the AMPS DAMA system.

Diversity control, terminal status reporting, and user dialling functions are already part of the AMPS design and are expected to be almost identical. Differences would be handled by the MSAT mode software.

4.10 MODEM

No change anticipated.

4.11 CONTROL FUNCTIONS

Because of the software controlled nature of these functions, this would be determined by the MSAT mode software design.

4.12 MECHANICAL CONSIDERATIONS

Mechanical considerations would also need to be addressed because of the changes described above. Some retooling would be necessary--the major items being the helical and coaxial filters as well as the extra 60W PA stages and heatsink.

5.0 CONCLUSIONS

Based on these design considerations, it is our opinion that a combined NBFM AMPS/MSAT mobile terminal is technically feasible and would be economically viable at a volume of 20K units annually. It is hard to imagine a more optimum cost approach for the mobile terminal than to modify an AMPS cellular baseline radio, a class of product which is expected to reach unprecedented volume levels for radiotelephone technology.

COSTS

Costs are shown as differentials to the baseline radio and are in 1981 Canadian dollars. Engineering costs are estimated based on $250/man-day ($50K/man-year). Material costs are based on a volume of 20K units annually.

	ENGINEERING				MATERIAL
	TOOLING	TIME		TOTAL($)	Cost per unit
		Man-years	$		
PA	50K	2	100K	150K	$200.
Pre-Amp	20K	½	25K	45K	50.
Duplexer	40K	2	100K	140K	50
MCLS Software	--	10	500K	500K	--
Miscellaneous	10K	1	50K	60K	20
	TOTAL			895K	$320

Cost differential = $320.

Selling differential = $725. (includes engineering amortization)