Preliminary

MARS 2.4GHz

Frequency hopping and Dual slot diversity description

History

Ver 0.1	JTP	980909	Initial version
Ver 0.2	FM	990111	Updated/changed for type approval
Ver 0.3	FM	990204	Updated/changed for type approval with new crystal

1. Introduction

The Mars system is based on DECT the ETSI standard ETS-300-175-1 to ETS-300-175-9. The Mars system is improved by implementing extra features to combat the interference at 2.4 GHz.
The frequency hopping method for 2.4 GHz ISM band has to provide optimal performance and connection quality in environment with 5 different types of interference:

1. Other interference of MARS-type, known hopping algorithm and avoidance method (synchronized/unsynchronized).
2. Microwave ovens, sweeping the most of the band and running on 60Hz mains supply.
3. Interference on fixed RF carrier, CW interference. Direct sequence CDMA is also detected as this type of interference.
4. Other hoppers using the ISM band, with unknown hopping algorithm, example: Wireless LAN based on IEEE802.11, etc.
5. “Range / multi-path propagation”

The frame format is based on DECT, but modified from 24 timeslots to 20 timeslots and 79/23/27/35 possible RF carriers. Frequency hopping is implemented on a frame by frame basis. The system is implemented with encryption based on DECT.

2. Avoidance method

2.1 Known hoppers

Use 79 RF channels. Re-map though hopping table. Part of RFPI/RPN defines which hopping sequence to use. Bearer hand-over: change of slot-position and hopping index. Avoid modulo 16 sequences (= DECT sequences).
Different connection/bearer should use different hopping index.

2.2 Microwave ovens

Use dual slot diversity. Transmission of same B-field content in two slots on different carrier. Normal one frame delay extended to 1.5 frames delay in each direction in order to ensure seamless selection of best received burst. Total extra round-trip delay is one extra frame.

2.3 CW interference on fixed RF carriers

Exclude discrete RF carriers and adaptive use of dual-slot diversity.

2.4 Other hoppers

Appears like random interference. Adaptive usage of dual-slot diversity.

2.5 Improve range / multi-path performance

Use prolonged preamble. In the base the frequency hopping sequence must be: RX – TX

3. Adaptation to 2.4GHz ISM band

3.1 Frame format:

Down-link (FP to PP) Up-link (PP to FP)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Symbol rate: 1.033570 Mbit/sec.
Frame length: 20 timeslots, same as 11.1458 msec.
Frame frequency: 89.72 Hz
Number of symbols for frame: 11520
Number of symbols per slot: 576 (440 in burst and 136 in guard space)

Frequency hopping frame begins from slot 10. Slots are used in pairs for duplex bearers (0,10), (1,11), etc. The same RF carrier used in up-link direction of a slot-pair in frame N is used in down-link direction in frame N+1.

Frequency versus slot

Frame	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
N											x		y							
N+1	x		y								z		w							
N+2	z		w																	

3.2 Burst format:

Sync field	A field	B field	XZ	Guard space

3.2.1 Sync-field

Length: up to 48 symbols consisting of

Possibly Prolonged preamble:	16 bit data
Preamble for bit-synchronization:	16 bit data
Frame synchronization word:	FP: E98Ah
	PP: 1675h

Pattern for transmission from FP:
1010 0101 1010 1010 1110 1001 1000 1010

Pattern for transmission from PP:
0011 0011 0011 0011 0101 1010 0101 0101 0001 0110 0111 0101

3.2.2 A-field

Total length 64 symbols
Header: 8 bit
Tail: 40 bit
CRC: 16 bit

3.2.2.1 T-MUX:

NT: RFPI is normally broadcast 7 out of every 8 frames.
QT: Static system information
PT: Broadcast, paging
MT: MAC layer control
CT: Connection oriented higher layer signaling

3.2.2.2 Derive hopping SeQuenceCode (SQC) from RFPI

In order to distribute usage of different hopping sequences, the actual used sequence is derived from the FP identity, RFPI. The RFPI is normally broadcast 7 out of every 8 frames which then allows immediate recognition of hopping sequence by the PP during the initial synchronization.

The RFPI consists of 40 bits (5 bytes):

E ARC					RPN

a8 a47

If the ARC equal 000 the RPN has three bits in length and is a Park type A, otherwise the RPN has a length of eigth and is.

E ARC					RPN

a8 a47

Two different positions of the SeQuenceCode (SQC) inside the RFPI is defined, in order to flexibility in deciding usage of same or different hopping sequence in multi-cell systems.

Option 0:
Park type A (residential):

E ARC	0					SQC

a8 a47
The SQC is located from bit a42 to a47.

Park type different from A:

E ARC	0					SQC

a8 a47
The SQC is located from bit a42 to a47.

Option 1:
Park type A (residential):

E ARC	1					SQC	

a8 a47
The SQC is located from bit a40 to a44.

Park type different from A:

E ARC	1				SQC	

a8 a47
The SQC is located from bit a34 to a39.

3.2.2.3 Excluding fixed carriers.

List of excluded RF carriers or parts hereof is broadcast using paging (reserved code 3). Two different methods are defined:

PT_3 (1): *EXCN0*[7], *EXCN1*[7], *EXCN2*[7], *EXCN3*[7] (28 bits used)
PT_3 (2): *ExcpPattern0*[32] (32 bits used)
PT_3 (3): *ExcpPattern1*[32] (32 bits used)
PT_3 (4): *ExcpPattern2*[15] (15 bits used)

$EXCN_x$ is the carrier number of an excluded RF carrier. Up to four individual carriers may be excluded using this method.
ExcpPatternx describes a complete pattern of excluded RF carriers.

3.2.3 B-field

Format and usage of B-field is similar to DECT. 320 bits of ADPCM data.

3.2.4 XZ-field

Format and usage of XZ-field is similar to DECT. X-field is a 4-bit CRC on the B-field content. Z-field is a copy of the X field and is used to detect sliding collision.

3.3 Frequency hopping algorithm

The number of used frequencies (NUF) in hopping algorithm is:

North America	79
Most of Europe	79
Japan	23
Spain	27
France	35

In FP and PP exists a PrimaryHoppingIndexNumber (PHIN). This number is incremented modulo NUF in the end of the normal downlink half-frame. It is broadcast in Q0 message instead of PSCN.

To a simplex or an established duplex bearer is assigned a HoppingIndexOffset (HIO), which is analogue to the used RF carrier in a FDMA system. This value is broadcast in place of CN in Q0 message. In the FP in all unused slots in up-link direction the receiver is scanning with HIO=0. The receiver scanning doesn't exclude RF-carriers.

Different FPs use different hopping sequences. The different sequences are derived from the hopping table by adding an offset, SeQuenceCode (SQC). This is a value in the range 0 – (NUF-1), extracted from the FP identity (RFPI).
A hopping table maps an index I to a carrier number: CN = f (I)

The physical RF carrier is calculated by the formula:

CN = (f ((PHIN+HIO) mod NUF) + SQC) mod NUF

3.3.1 Excluded carriers

Excluded carriers (exceptions) are fixed carriers that constantly are interfered by CW RF-carrier. The decision for excluding a RF carrier, are based on:

- RSSI monitor during scanning in the FP.
- Bearer quality in FP correlated to specific RF-carriers.
- Bearer quality detected in PP and reported using Q1 in MAC-header.

When exception carriers are included the complete algorithm is:

```
I  =  (PHIN+HIO) mod NUF
CN  = ( f (I) + SQC ) mod NUF
While CN in ExclusionList
{
  I  =  I + ((FrameNumber16 / NUF) mod (NUF-1)) +1
  CN  = ( f (I) + SQC ) mod NUF
}
```

3.3.2 Hopping tables

Three different hopping tables are defined.

3.3.2.1 Hopping sequence for North America and most of Europe

Frequency: 2400.983 + CN * 1.033570 MHz

i	f(I)	i	f(i)	i	f(i)	i	f(i)	i	f(f)	i	f(i)	i	f(i)	i	f(i)
0	0	10	76	20	18	30	34	40	14	50	20	60	48	70	55
1	23	11	29	21	11	31	66	41	57	51	73	61	15	71	35
2	62	12	59	22	36	32	7	42	41	52	64	62	5	72	53
3	8	13	22	23	72	33	68	43	74	53	39	63	17	73	24
4	43	14	52	24	54	34	75	44	32	54	13	64	6	74	44
5	16	15	63	25	69	35	4	45	70	55	33	65	67	75	51
6	71	16	26	26	21	36	60	46	9	56	65	66	49	76	38
7	47	17	77	27	3	37	27	47	58	57	50	67	40	77	30
8	19	18	31	28	37	38	12	48	78	58	56	68	1	78	46
9	61	19	2	29	10	39	25	49	45	59	42	69	28		

3.3.3 Example.

This example shows receive and transmit frequencies in a number of consecutive frames. The example is seen from the FP side with two simultaneous connections. Transmission is indicated in bold.

Used hopping table: North America
Excluded RF carrier: 11
SeQuenceCode (SQC): 3
HoppingIndexOffset (HIO): 0 and 2

Frequency versus slot

Frame	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	PHIN
N			**49**		**26**						3	3	3	3	65	3	3	3	3	3	0
N+1			**3**		**65**						23	23	26	23	46	23	23	23	23	23	1
N+2			**26**		**46**						62	62	65	62	46	62	62	62	62	62	2
N+3			**65**		**46**						11	11	46	11	19	11	11	11	11	11	3
N+4			**46**		**19**						46	46	46	46	74	46	46	46	46	46	4

3.4 PP synchronization procedure

PP selects a random RF carrier and tries to receive a frame within 0.9 sec. If nothing is received then a new RF carrier is selected.
When a burst with correct A-CRC is received and it is a Nt (RFPI) the hopping sequence (SQC) is known and the PP must receive in the following frames using the hopping sequence. If the received A-field is different from a Nt, the PP selects a new RF carrier randomly and waits for Nt. In this state the PP do not have information of excluded RF carriers, but just follows the known hopping sequence without excluding any RF carriers. Only individual frames are missed on the excluded carriers. When PT3 is received, the PP is able to receive on exception carriers.

3.5 Dual slot diversity

Dual slot diversity is activated in case interference is detected. That is, two bearers are active, carrying the same B-field content. The receiver decides which of the received speech frames to use, depending on A-CRC and/or X-CRC. The setup and release of the 2nd bearer are performed dynamically by the FP-MAC and PP-MAC to adapt to current interference level. The two bearers are managed independently in the MAC, like a stalled intra-cell bearer hand-over with two established bearers. HoppingIndexOffset (HIO) for the two bearers are selected independently.

3.6 Power amplifier activation

3.6.1 External connection

The FP has one connection active at all times to make synchronization of the PP possible. In case a speech connection is active one slot will be active in down-link direction and one slot will be active from in up-link direction. The power amplifier will be active from start of sync field to the end of XZ field, which is slightly less than 1/24 of the total frame. In case dual slot diversity is active, two slots will be active equal to 2/24 of a frame.

3.6.2 Internal connection

Two handsets are able to make an internal connection. In this case two bearers will be active in the down-link direction from FP, and one bearer will be active from each handset. The two bearers in down-link direction are not correlated and uses different HoppingIndeOfffset. Dual slot diversity is activated independently towards each handset, i.e. up to four bearers may be activated in down-link direction, and two bearer may be active in up-link direction.

Flow Chart and technical description

Sirius Remote
&
Base Station

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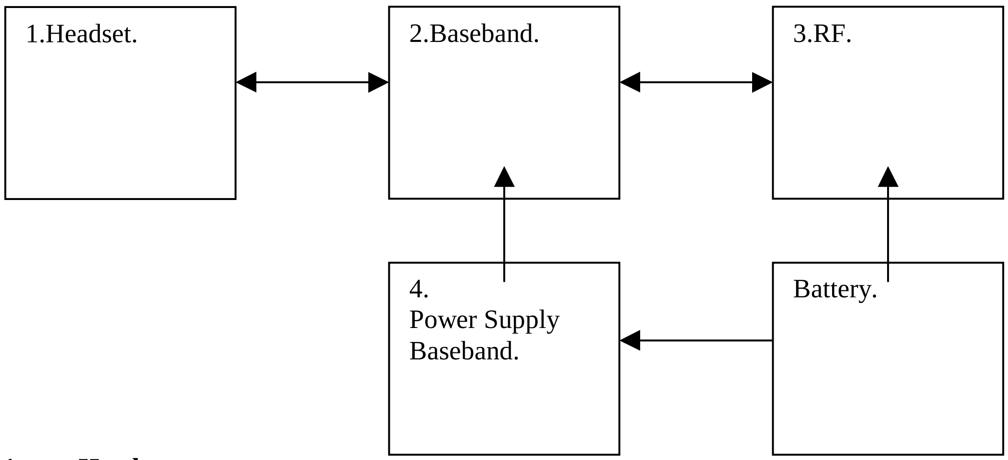
4. Flow chart for the Remote.

This document describes the design of the Base station.



4.1 Headset:

The headset is connected to J5, which is integrated on the PCB.

4.2 Baseband:

<u>Microcontroller.</u>
The micro/burstmode controller IC2, is a device containing both the microcontroller and MARS digital/analog interface.
The clock frequency for the microcontroller is 9.048436 Mhz it is possible to tune the crystal with the capacitor diode D1 who is controlled by the mircontroller.
The serial interface is bi-directional interface, it is protected for ESD and EMC by R16 and C38.

<u>Burst Mode Controller.</u>
The burstmode controller (BMC) inside the microcontroller performs all the time critical control functions as well the audio interface to the transducers.
The clock signal is generated by a crystal oscillator controlled by the crystal X1. The frequency is nominally 9.048436MHz, but can be finetuned by the capacitordiode D1, which is controlled from an analog output from the microcontroller.
There are 3 different supply inputs on the BMC, one for the digital circuits (VDD), one for the analog circuits of the RF interface (AVD) and one for the analog part of the codec (AVD2). The two analog supplies have been decoupled separately to reduce the noise levels.
The interface to the transducers (microphone and earpiece) consists of the codec placed internally in the BMC and some external passive components to decouple the low frequency- and the RF noise. The microphone in the GN headset is an electret type, which requires a supply current. This is supplied through R13 and R14. When the handset is in standby the VREF outputs will be powered down, so that the microphone will consume no power in this mode. The earpiece is coupled differentially to the loudspeaker outputs LRS+ and LRS-.

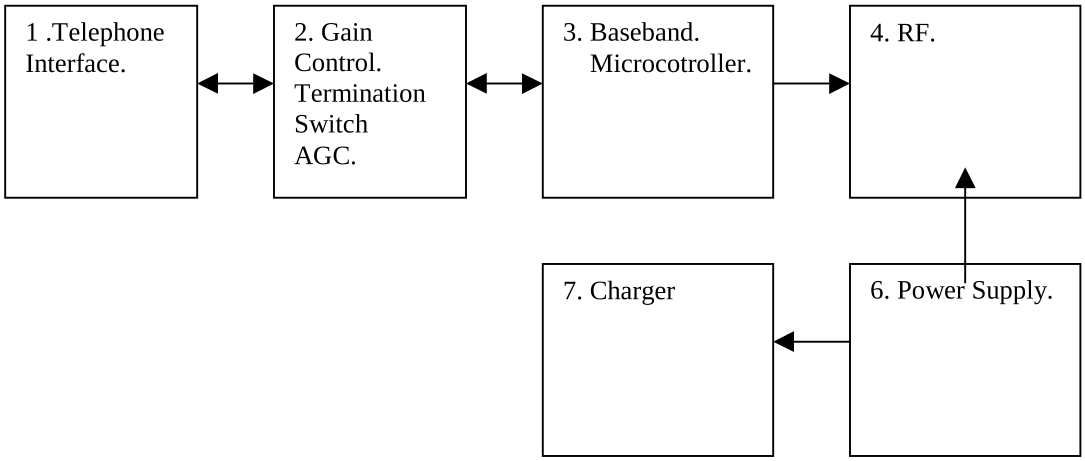
4.3 RF: See "Circuit description for the RF part".

4.4 Power supply baseband:

The power supply for the base band part consists of IC1 and some decoupling capacitors. The regulated output voltage from the regulator IC1 is 3.0V. When the input voltage is below a threshold voltage determined by IC2 the regulator will be turned off, resulting in a current consumption of less than 5uA to protect the batteries against deep discharge. The reset pulse is generated by R1 and C4.

5. Flow chart for the Base station.

This document describes the design of the Base station.



5.1 Telephone interface:

The signal from the telephone is connected to J2 and the receiver is connected to J3. With the two relays RL1 and RL2 is possible to route the signal from J2 to J3 or from J2 to the analog interface.

5.2 Gain control, Termination switch:

The in/out signals from the telephone interface goes to the switch S1, where it is possible to switch between 7 different configuration of the wiring in the telephone. S3 switches the MARS system on and off.
T5 is an insulation transformer. The output from the transformer is supplied to the input of the burstmode controller and the differential amplifier IC8A. The output from the amplifier is rectified and the DC is filtered by C66. R47 and R41 give the time constant of the charging and decharging of C66. IC8B is used as a buffer. The DC signal, which is a function of the AC input signal, is supplied to an AD converter in the microcontroller. Inside the burstmode controller is a input attenuator which has 15 steps of 2 dB attenuation. The attenuation is controlled by the microcontroller as a function of the level of the DC signal, this gives an AGC function so the output signal level is constant to the portable part. If the input signals suddenly drops more than 20dB, the AGC function is stopped, so regulation only is made is there is an input signal.
The differential output signal from the burstmode controller is supplied to the resistor network R58, R59, R55, R56 and R120. With the switch S2 is it possible adjust the TX gain, which gives 8 steps. T6 and T7 is a push pull output buffer, so it is possible to source signal to low impedance.
Inside the burtsmode controller there is a 15 step / 1dB step attenuator. The TX gain switch S2 gives a code depending on the position of S2. This controls the attenuator, so the TX gain can be adjusted over a range of 50dB.

5.3 Baseband, Microcontroller:

Microcontroller.
The microcontroller IC3 is configured to run in “Memory Expansion Mode” where the processor is controlled by the external ROM. If a processor with internal ROM is used, the processor is used in the “micro controller mode”. The “start up” mode is determined by R19 and R20. The clock frequency for the microcontroller comes from the burstmode controller. During and shortly after reset the clock frequency will be 1.1311MHz. During normal operation the clock frequency will be 4.5242MHz. The circuits needed for selecting the flashprom and the burstmode controller is built into the processor.

Burst Mode Controller.
The Burst Mode Controller (BMC) IC 1 performs all the time critical control functions as well as the audio interface to the audiointerface.
The clock signal is generated by a crystal oscillator controlled by the crystal X1. The frequency is nominally 9.048436MHz, but it can be finetuned by means of the capacitordiode D2 controlled from an analog output from the micro controller. There is more clock outputs from the BMC. UCLK is the clock output to the microcontroller. CLK1M is a 1.0054MHz clock output, which not is used in the base station. CLK100 is not used in the construction but connected to a test point. CLK100 is a 89.17Hz clock signal which is synchronized to the MARS frame, so it is useful for synchronizing e.g. an oscilloscope. RFCLK is a 9.048436MHz clock output for the PLL in the RF module. It is only active during the PLL lock period.
There are 3 different supply inputs on the BMC, one for the digital circuits (VDD), one for the analog circuits of the RF interface (AVD) and one for the analog part of the codec (AVD2). The two analog supplies have been decoupled separately to reduce the noise levels.
The interface to the audio interfaces consists of the codec placed internally in the burtstmode controller and some passive components used to decouple for the low frequency and the RF noise.

5.4 RF: See “Circuit description for the RF part”.

5.5 Power supply:

The power supply for the base band part consists of two low drop regulators. The discrete voltage regulator (T13) delivers an output voltage of 4V. This supply is used to supply the RF module. The voltage regulator IC9 delivers an output voltage of 3,3V at Vcc. It supplies the digital and the analogue circuits of the base band , as well as some parts of the RF module. The regulator IC9 contains a comparator and a voltage reference, this is used to make a power up reset, where C74 and R60 gives the timing of the reset pulse

5.6 Charger:

There are 2 chargers, which are identical so only one is explained. The charger is a 2 step charger, one for low current charging and a high current (250mA) constant current charger controlled by the microcontroller. The low current charger is made with a voltage drop resistor R29, R30. The battery voltage is measured with an A/D converter in the microcontroller. When the portable part is placed in the base, the output voltage from the charger drops, this is detected by the microcontroller activating the charging algorithm and turning the charging indicator on.
T9, T19, T2, R36, R35, R26, R27 and R28 are coupled as a constant current generator, controlled by T10 and the microcontroller. The battery voltage measured by the microcontroller by R73, R74 and C37. D13 is a protection diode. With R76 and R88 it is possible to measure the temperature of the battery during charging.

MARS 2.4GHz

Description of transmitter and receiver architecture

6. Overview

The MARS system is a frequency hopping system.

7. Baseband

The baseband circuit consist primarily of a microcontroller and a DECT baseband processor (Two different are used for the base and handset respectively).

The baseband processor handles all audio, signal and data processing needing in a handset/base. The baseband processor includes CODEC and ADPCM coder/decoder. The baseband processor for the base also includes an echo chancellor and an echo suppressor.

The baseband controller also include a Burst Mode Controller that performs the generation and decoding of the frames used. The BMC also generates the control signals for the radio part. The bit rate is 1.033570 Mbit/s.

The baseband processor has a gaussian filter to perform the gaussian filtering of the transmitted data. The output signal (TRADAT) is an analog signal.

The base processor has a comparator to transform the analog RECDAT signal to a digital signal. The data and clock recovery circuit extracts the timing information from the received signal.

8. Transmitter

The MARS system uses the open loop modulation scheme. In the guard band between two slots, (136 bittimes) the synthesizer is programmed with the new data and the PLL obtains phase lock on the desired frequency. Just before the PA is powered up the synthesizer is powered down and the phase detector output is tri-stated. Thus, the VCO runs freely during the transmission with the frequency determined by the voltage on the loop capacitors.

It is now possible to modulate the VCO with an analog signal (TRADAT) at its modulation input.

The VCO signal is doubled in the RF chip. After the doubler, a driver amplifier is used to obtain the correct power level for the PA. The doubler and driver amplifier is turned on in the guard band during the lock-in time. The PA is only turned on when a burst is transmitted. The power up and power down of the PA is slowed down to reduce the generated switching spectrum.

There is a TX-RX switch to switch the antenna between the PA and the LNA. Between the TX-RX a BPF (ceramic) is used to perform some filtering.

In the base station, a diversity switch is implemented to switch between to antennas. A circuit is implemented to use the best antenna for receiving the signal. The choice is based on the measured RSSI value from a few bits in the preamble.

In the base station there are two internal antennas. There is no indented gain in the antennas.

In the handset an internal inverted F antenna is used. This antenna has a gain of omni-directional antenna pattern.

9. Receiver

The front-end consists of the antennas, bandpass filter and TX-RX switch as described in the transmitter section. There is also a single transistor LNA before the second bandpass filter (ceramic).

The mixer is internal in the RF chip. The LO signal comes from the doubler used in the transmitter.
The VCO is band-switched, so a different mode of the VCO is used for RX and TX. The PLL and doubler are common for the TX and RX path. This is possible as the transceiver only operates in either TX or RX mode.

The down-converted signal has an frequency of 110.592 MHz. The IF signal is filtered in a SAW filter with a approx. 1.2 MHz bandwidth. The SAW filter gives most of the channel selectivity. After the filter a limiter and a discriminator is used. The discriminator has a LC tank centered at the IF.
The demodulated signal is lowpass filtered with RC filter to obtain a better channel selectivity and noise reduction. The lowpass filter has a cut off frequency of approx. 500 kHz.

A sample and hold circuit is used to extract the DC offset of the received data to improve the comparator performance. The received data is sampled in the preamble where the alternating sequence ensures a correct average value.

10.Frequencies

The crystal used has a frequency of 9.302131 MHz. The microcontroller runs on this frequency or a fraction of this.

During transmission is the VCO half the transmitted frequency.

The IF frequency in the receiver is 110.592 MHz. The MARS system uses the lower LO signal. The same VCO is signal is doubled and used as LO signal. The frequencies in the system are as follows.

The channel spacing is 1.033570 MHz

All frequencies are given in MHz

Channel	TX VCO freq.	TX freq.	RX VCO freq.	RX LO freq.	IF
0	1200,492	2400.983	1145,196	2290,391	110.592
40	1221,163	2442.326	1165,867	2331,734	110.592
79	1240,801	2481,602	1185,505	2371,010	110.592