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Portable Radio with PLL Frequency Synthesizer

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Recently, in the business radio market in the U.S., PLL synthesized frequency system has become popular, and radios with advanced and multiple functions are demanded, in step with rapid progress in microprocessor technology.
Fujitsu TEN has already put the 3092 series phase-locked loop (PLL) mobile radios on the market, and proceeded to develop a PLL portable radio to expand the series. The portable radio Model FTP40-592H of small size and high reliability employs a PLL frequency synthesizer, and is aimed at multiple functions and high performance to please the customer, and an alignment-free wide band radio for dealers.

1. Introduction

In recent years, technological innovation in the field of two-way radios has remarkably advanced, and the phase-locked loop (PLL) frequency synthesizer has become popular, replacing the multiplier with crystal oscillator.

Especially in the market in the U.S., the PLL frequency synthesizer has advantages since multichannel radios are generally used. A characteristic of the American market is that portable radios, as well as mobile radios, are in wide use.

Considering this situation, we have developed a 400-MHz band portable radio to expand the 3092 series mobile radios which have been on the market and which were given a favorable reception. This portable radio employs a PLL frequency synthesizer and is provided with multiple functions with a built-in microprocessor. Adjustment in the band used is unnecessary due to wide-band design, thus reducing the manpower required for adjustment and test by dealers.

This article gives the outline, features, and key points of design of the 400-MHz band PLL portable radio Model FTP40-592H.

Table 1. Aims of development

Dealer requirements	Reduction of lead time Stock of quartz crystal units not required	→	PLL frequency synthesizer
	Adjustment before delivery not required	→	Wide-band design
User requirements	Improved operation and functions	→	"User friendly" design (built-in microprocessor)
	Longer battery life	→	Low power consumption (CMOS IC)
	Small size	→	Optimized circuit
	High reliability	→	Parts selection (Flat package IC, power module 2125-type chip components)
	Low price	→	

2. Aims of development

The aims of development of this radio are listed in Table 1.

In the U.S., multichannel radios are widely used for business in various modes, such as connection to a telephone line. Under such environment, radio users require multiple functions and high performance.

To make the most of the functions, easy operation is necessary, including easy-to-use mechanism.

Development of this radio aims at realizing "user friendly" design, which involves the above-mentioned conditions.

For radios employing a PLL frequency synthesizer, a ROM in which data can be written immediately is installed instead of a quartz crystal unit which was purchased for each frequency assigned to users. This change is advantageous to dealers concerning lead time and inventory. However, it is still necessary for the dealers to perform adjustment before delivery.

Figure 1 shows the general flow from manufacture of radios for the U.S. market to delivery to users. In general, radios adjusted for the factory test frequency are delivered to dealers and stored. Each dealer writes the frequenies assigned to the user by the Federal Communications Commission (FCC) into ROM, and installs the ROM in the radio. After that, the dealer adjusts and tests the radio at the user's frequency, then delivers it to the user.

For ordinary circuit design, a radio adjusted at the factory satisfies the specifications only within a few MHz from the adjustment frequency. For this reason, the radio must be adjusted and tested again at the assigned frequencies.

For the new portable radio that we developed, wide-band design is applied to the voltage-controlled oscillator (VCO), transmission radio-frequency circuit, and reception radio-frequency circuit. With this design, the radio adjusted at the factory satisfies the specifications throughout its frequency range (20-MHz band width from 450 MHz to 470 MHz). As the result, the dealer can decrease the manpower for delivery adjustment and the number of adjustment engineers.

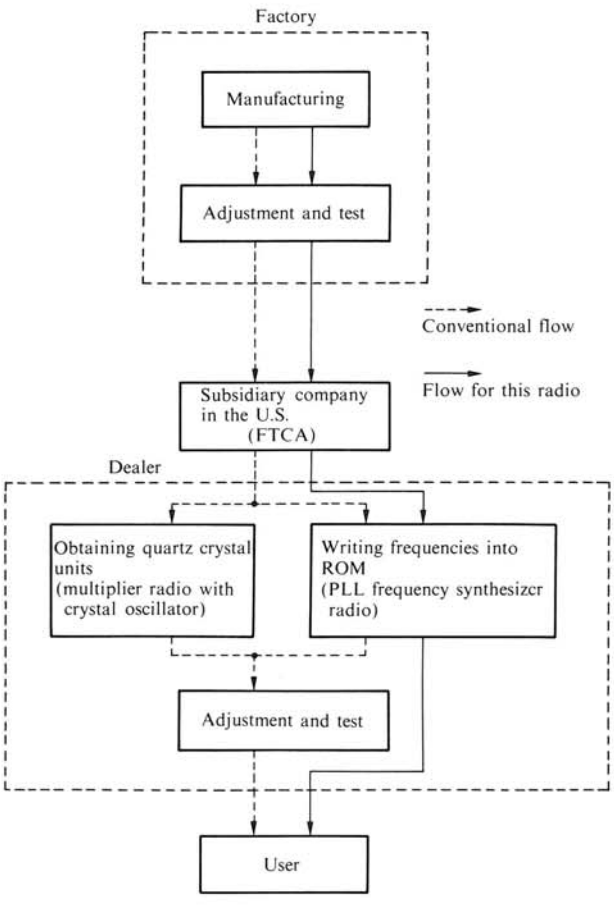

Figure 1. Shipment process of radio for the U.S.

Figure 2. FTP40-592H portable radio

3. Outline of equipment

This equipment is a 400-MHz band portable business radio in which we used PLL frequency synthesis and microprocessor for the first time. There are several differences between this equipment and other existing portable or mobile radios.

The appearance is also novel, as shown in Figure 2.

3.1 Specifications

Tables 2 and 3 respectively show the rating and performance of this equipment.

3.2 Features

1) Transmitter power ouptut can be selected (5 W or 2 W)

Usually, a rechargeable nickel-cadmium battery is used as the power source for portable radios. As battery charging is troublesome, it is desirable for the battery to work as long as possible.

In this radio, RF power output can be switched from 5 W to 2 W (for short-distance communication etc.), thus decreasing the current drain and extending the battery life.

2) 16-channel PLL frequency synthesizer

With the diversification of radio use, requirement for multiple channels has increased. For conventional crystal frequency multipliers, since a quartz crystal unit is required for each channel, the cost is high and additional installation space is required. The FTP40-592H portable radio makes up to 16 channels available by using a PLL frequency synthesizer and a small electrically erasable programmable ROM (EEPROM).

For repeat use, semi-duplex mode, in which the transmitter frequency is different from receiver frequency for each channel, is available. Continuous tone coded squelch system (CTCSS) frequency can also be set separately for transmission and reception.

3) Built-in microprocessor

The built-in 4-bit microprocessor containing an 8K-byte ROM enables channel scanning, priority scanning, transmission timer function, and CTCSS function.

4) Volume/squelch control with push buttons

Electronic controls (variable attenuators) with push-button switches are used instead of rotary controls to control volume and squelch, thus simplifying operation and renewing the design.

5) Large-size liquid crystal display (LCD)

Since radios came to have multiple functions, it

Table 2. Ratings of FTP40-592H radio

Item	FTP 40-592H
Frequency	16 channels between 450 and 470 MHz
Maximum channel space	20 MHz
Channel separation	12.5 kHz
Type of emission	16KOF3E
Modulation deviation	±5 kHz
Antenna impedance	50 Ω
Communication method	Push-to-talk system (semi-duplex mode possible)
CTCSS encoder/decoder	EIA tone 38 frequencies
Receive method	Double superheterodyne
Power supply	12 VDC/7.2 VDC Nickel-cadmium battery
Operating temperature range	−30°C to +50°C
Dimensions	With 7.2 V battery pack attached: 220(H) × 64(W)× 36(D) mm
Weight	Approximately 16 oz.(without battery)

Table 3. Performance of FTP40-592H radio

Item	FTP40-592H
[Transmitter]	
RF output power	5 W/2 W
Frequency stability	$\pm 5 \times 10^{-6}$ or less
Spurious emissions	−60 dB or less
Audio distortion	5% or less
FM hum & noise	40 dB or more
Current drain	Approx. 1.6 A
[Receiver]	
Sensitivity (12 dB SINAD) (20 dB quieting)	0.3 μ V 0.4 μ V
Selectivity	70 dB or more at 25 kHz band width
Spurious rejection	60 dB or more
Intermodulation	60 dB or more
Distortion	5% or less
Audio output	0.6 W
Current drain	Approx. 0.2 A

is important to inform the user of the equipment status and setting. For this purpose, a large liquid crystal display (LCD) is used to display channels and various statuses. In addition, back lighting with LED makes the LCD easy to read at night.

6) Environment-proof design

Portable radios are used in various environments.

For example, good communication is required even in noisy places such as construction sites. To satisfy such requirement, this radio is equipped with a large 50 mm diameter speaker delivering maximum voice output of 600 mW (30% higher than other portable radios of this company).

It is also necessary to prevent rain damage to radios. In the FTP40-592H portable radio, a film-cone loudspeaker is used instead of a paper-cone speaker, and rubber switches are used for waterproofing.

7) Small size

Besides improved functions and performance, portable radios should be handy to carry.

By using flat package ICs and small chip components 2 mm × 1.25 mm, we were able to double the components packaging density as compared to our other portable radios, and the equipment could be made small.

8) Quick attach/detach battery pack

The battery pack attaches at the bottom of the body; it can be attached/detached by rotating it 90°, making battery replacement quick and easy. Two types of battery pack (a large pack for 5 W/2 W transmitter output, and a small pack for 2 W only) can be selected according to the purpose.

9) Plentiful options

In the U.S., business radios can be connected to public telephone lines. In this case, the radio must be equipped with a push-button dial. For this function, the dual tone multi-frequency (DTMF) encoder and other optional units can be installed in this radio.

10) Die-cast aluminum cabinet

Portable radios have to be sturdy. Design considering sufficient heat radiation is required to maintain transmitter output of 5 W.

To satisfy these requirements, monolithic molding die-cast aluminum, which is solid and has good heat radiation, is used for the cabinet.

3.3 Configuration and operation

This equipment consists of the PLL frequency synthesizer unit, transmitter/receiver unit, and control unit. The PLL frequency synthesizer unit contains the transmitter/receiver audio circuits.

Figure 3 is the block diagram of this radio.

3.3.1 PLL frequency synthesizer unit

1) PLL frequency synthesizer

The PLL frequency synthesizer consists of the following:

- VCO circuit
- Prescaler (DIVIDE)
- PLL controller circuit, including variable frequency divider, phase comparator, and reference oscillator
- Low pass filter (LPF)

The PLL frequency synthesizer receives control signals from the microprocessor, and outputs 400-MHz band radio-frequency signals at the transmitter carrier frequency and receiver first local oscillator frequency.

Low-power type IC's are used for the prescaler to decrease the current drain. By changing the shield structure, we reduced the VCO size to one-fourth of the VCO size in existing mobile radios, while obtaining the required performance.

2) Transmitter/receiver audio section

The transmitter/receiver audio section consists of an audio circuit for modulator (AF-AMP3), noise squelch circuit (N-AMP), electronic volume control circuit (ATT), and tone LPF circuit.

The audio circuit for modulator amplifies sound signals from the microphone, and supplies them to the VCO modulation terminal. The noise squelch circuit detects signal input through receiver noise. The electronic volume control circuit switches the attenuator by control signals from the microprocessor to adjust the volume and squelch level. The tone LPF circuit rejects unnecessary elements from CTCSS signals.

3.3.2 Transmitter/receiver unit

1) Transmitter section

The transmitter section consists of the exciter (RF-AMP1), final power amplifier (RF-AMP2), LPF, and APC circuit.

The transmitter section amplifies the PLL fre-

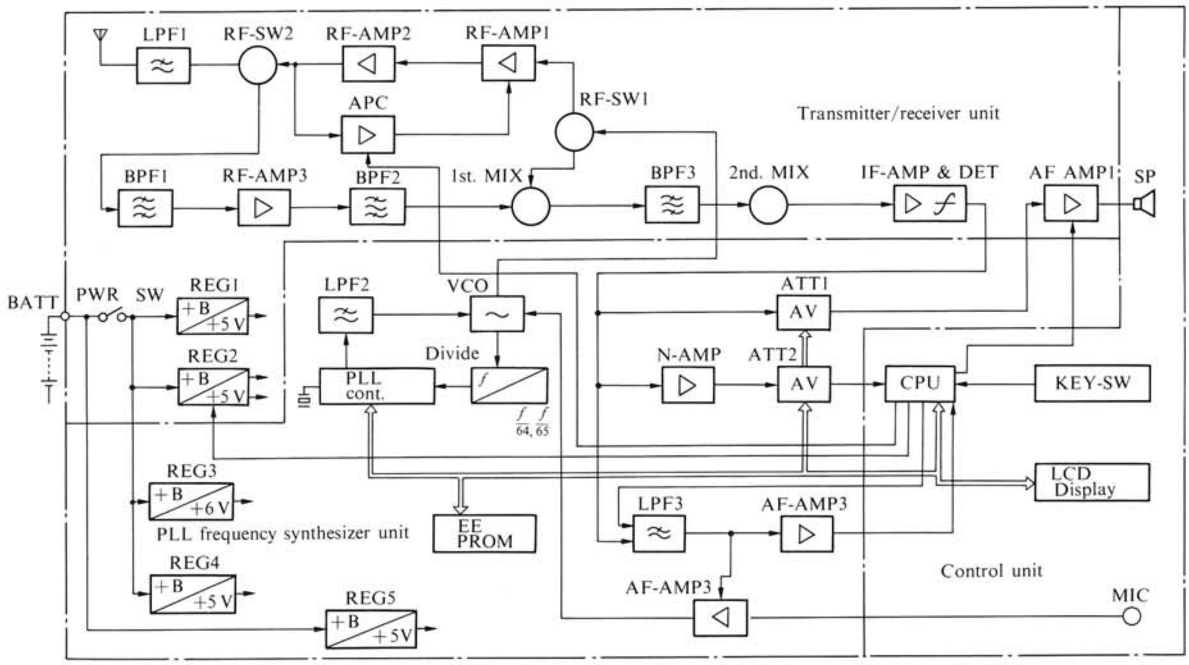

Figure 3. Block diagram of FTP40-592H

quency synthesizer output (about 1 mW) to the rated transmitter output. The APC circuit keeps the transmitter output constant. It also switches the transmitter output to 5 W or 2 W by control signals from the microprocessor.

2) Receiver section

The receiver section consists of a radio-frequency amplifier (RF-AMP3), mixer (MIX), intermediate-frequency amplifier (IF-AMP), demodulator (DET), and audio amplifier (AF-AMP1).

The receiver section performs frequency conversion for received signals in the double superheterodyne process, then performs FM detection and amplification to operate the speaker.

3.3.3 Control unit

The control unit consists of a 4-bit microprocessor, LCD controller, LCD, EEPROM, and a key switch. The CPU recognizes switch operation by the user, and controls the corresponding operation of the equipment.

4. Key points of design

The following describes the key points of the wide-band design achieving adjustment-free equipment and the "user friendly" design with multiple functions and easy operation.

4.1 VCO circuit

The VCO is an important part of wide-band adjustment-free equipment using the PLL frequency synthesizer.

The VCO is the most important circuit of those composing the PLL circuit. Noise in the VCO output deteriorates the following characteristics:

- For transmission: S/N ratio, occupied bandwidth, spurious radiation, etc.
- For reception: S/N ratio, blocking effect, etc.

To avoid such deterioration, the following points were given much weight in designing a VCO aiming at wide-band adjustment-free and small size equipment:

- Decreasing phase noise in VCO
- Improving frequency stability
- Decreasing noise from outside VCO
- Preventing mechanical vibration

Figure 4 shows a modified Colpitts oscillator, which is the basic circuit of the VCO that we designed. The actual circuit consists of the following:

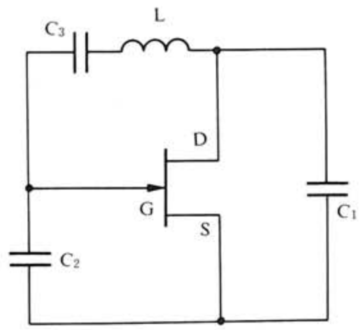

Figure 4. Oscillator equivalent circuit

- Active element: Junction type FET
- L: Air-core coil
- C_1, C_2: Ceramic capacitors
- C_3: Composite capacitance of varicap diode, trimmer capacitor, and ceramic capacitor

The oscillation frequency of this circuit is represented by the following formula:

$$f \fallingdotseq \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}\right)}$$

In the VCO, control voltage V_R applied to the varicap diode changes capacitance Cj. As a result, C_3 changes, causing oscillation frequency f to change.

For wide-band adjustment-free equipment, therefore, it is necessary for the oscillator frequency to change by 20 MHz (frequency band width used) or more within the range of control voltage that can be applied.

Because the upper limit of control voltage is limited by power supply voltage, it is difficult to achieve wide-band coverage in a portable radio, whose battery voltage is lower than that of a mobile radio. Voltage can be raised by using a DC-DC converter, but this method causes some problems such as noise generation.

As the means to achieve wide band in this radio, we decided to increase the voltage sensitivity of the VCO. Therefore, we designed the circuit so that varicap diode capacitance Cj would contribute more to C, which determines the frequency of the LC oscillator.

1) To increase the contribution of Cj to C_3,capacitance in parallel with Cj was eliminated and series capacitance was increased.

2) As C_3 capacitance increased, L was made smaller to obtain the required oscillation frequency.

3) Capacitors and the coil were optimized considering the following:

- Capacitance required for the trimmer capacitor for frequency fine adjustment and capacitance required for the capacitor for switching transmission/reception frequency
- Ratios of these capacitors' capacitance to Cj
- Frequency stability

As the result, we obtained voltage sensitivity about four times as high as that of VCO of ordinary mobile radios, as shown in Figure 5, and adjustment-free equipment could be developed.

4.2 Wide-band Transmitter

The transmitter directly produces the 400-MHz band carrier frequency by VCO. This method enabled removal of the narrow-band tuning circuit for eliminating spurious radiation. (This circuit is usually required for frequency multiplying-type radios and mixer-type PLL radios.)

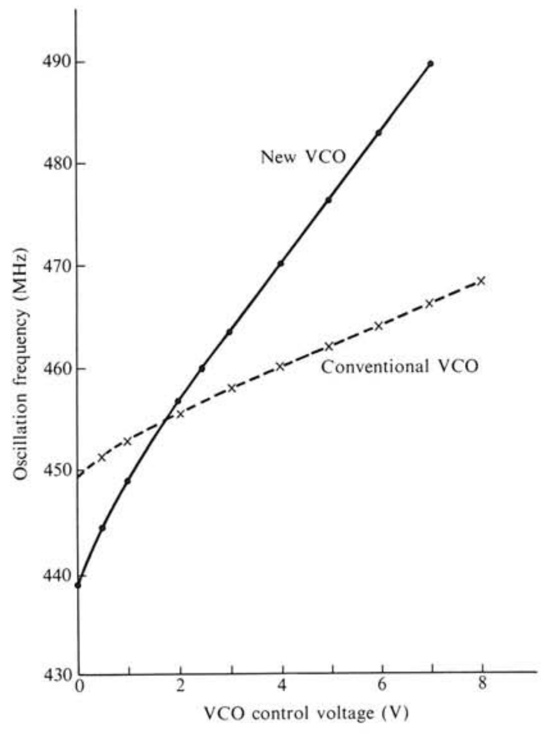

Figure 5. Voltage sensitivity of VCO

In the power amplifier, a strip line on an alumina ceramic printed circuit board is used, and a wide-band adjustment-free small-size power module (HIC) is adopted.

4.3 Helical resonator

To achieve an adjustment-free radio, the front end and first local oscillator must be wide band, for the receiver is a superheterodyne, and the first mixer and subsequent circuits can be narrow band.

For the front end, which greatly influences the performance of the receiver, a high-performance helical resonator is used as the band-pass filter (BPF). This helical resonator determines the front end band width.

To make the pass band width of this BPF 20 MHz or more, a newly-designed triple-tuned helical resonator was adopted. Figure 6 shows the frequency characteristics of the double-tuned helical resonator used in conventional mobile radios and the triple-tuned helical resonator used in this radio. The double-tuned resonator in this figure is adjusted at 460 MHz. For example, to use the equipment at 450 MHz, loss increases (approx. 8 dB) and readjustment is required.

For wide-band characteristics, the tuning circuit tends to reduce image frequency ($fs = fr - 2fi_1$) rejection. To improve this reduction a sharp attenuation characteristic can be obtained with triple tuning, and the first intermediate frequency (fi_1) is higher than in conventional equipment.

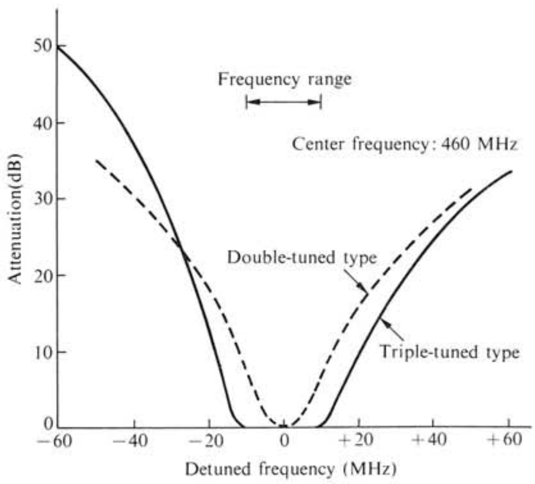

Figure 6. Frequency characteristics of helical resonators

The newly-designed helical resonator is triple-tuned. Nevertheless, by adopting a tuning structure without a trimmer capacitor, the resonator size could be reduced by about 50% as compared to the double-tuned helical resonator in other portable radios manufactured by this company.

The narrow-band tuning circuit for eliminating spurious response could be removed by using 400-MHz band VCO output as the first local oscillator signal.

4.4 Microprocessor

4.4.1 Hardware

To develop a small multi-function/high-performance portable radio, a newly-designed one-chip microprocessor was adopted. This microcomputer contains an 8K-byte mask ROM; the largest capacity of those for 4-bit CPUs. The software is enhanced with this ROM, and various I/O controls are made possible with the 80-pin flat package.

To control advanced peripheral ICs adopted for achieving multiple functions and high performance, it is necessary to send a large amount of data from the microprocessor. To decrease the number of signal lines between the microprocessor and peripheral ICs and to improve reliability and for small size, data is transferred by the method explained below.

1) Control data in serial data format synchronized with clock signals is sent to the ICs subject to control, through three signal lines.
2) Three signal lines are usually required for each peripheral IC subject to control. In this portable radio, the number of signal lines was decreased by the serial bus method using common clock data signal lines. (See Figure 7)

4.4.2 Software

The main functions performed by microprocessor software are explained below.

1) Channel scanning

For a two-way FM radio using several channels, the channel on which it is called may be unknown. Unlike FM broadcasting, the time at which remote signal is sent is also unknown. Therefore, it is hard to find the distant station by channel up/down operation. The channel scan function is effective in

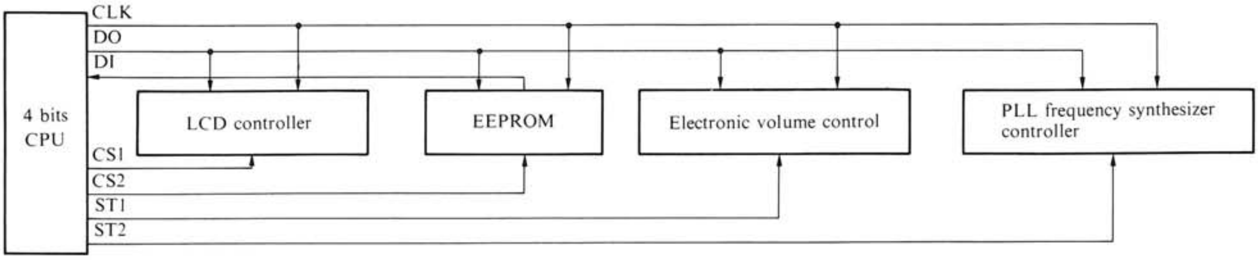

Figure 7. Serial bus type signal transmission

such case. With this function, channels are sequentially scanned, and scanning automatically stops at the channel on which there is a signal.

When connected to the telephone line, a free channel of repeater station is sought, and the call is made using that channel. If the inactive mode is selected for the channel scan function, scanning stops at a free channel.

2) Priority channel

When multiple channels are used for communication, it may be necessary to use a specific channel for a specific purpose, (e.g. sending important information, emergency communication, communication with dispatcher station). It is necessary that this channel (priority channel) be easier to access than other channels.

In this portable radio, the following priority is given to the priority channel so that it can be accessed easily:

① Pressing the priority key immediately switches from the current channel to the priority channel.
② Pressing the push-to-talk (PTT) switch during channel scan switches from scanning channel to the priority channel.
③ Calls on the priority channel can always be monitored by the priority scan function.

3) Priority scanning

When important information is sent through the priority channel, the information cannot be received if the receiver is using another channel.

The priority scan function is used to avoid such a case. This function checks the priority channel at regular intervals during recieving, standly or channel scanning. If a signal is detected, the receiver switches from the current channel to the priority channel. (See Figure 8)

The scan interval during receiving is made longer than that during standly so that conversation is not interrupted frequently.

4) Push-button volume/squelch control

Volume and squelch can be set in eight steps by push buttons. The LCD, which is usually used to indicate channels, indicates volume or squelch level when the volume/squelch key is pushed.

The volume key is used as the squelch key by pressing the shift key first. Pressing the squelch once changes the level by one step. If the squelch key is pressed repeatedly, the level changes in multiple steps. In this case, shift operation is held for about two seconds to simplify the shift operation.

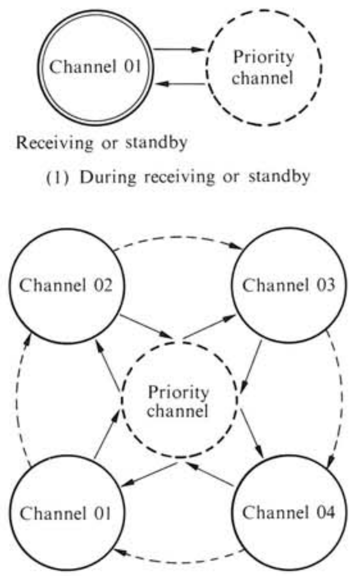

Figure 8. Example of priority scan

5) Memory backup

For the currently selected channel, volume level, and channel scan status, it is desirable that the previous status should be kept even if the power is turned on/off. For this radio, the microprocessor detects power-off, and the stand-by mode with low power consumption is set. With this function, the above status can be preserved for one day or more even if the battery pack is detached.

6) Two-mode user program

The user can freely set channel scan, priority channel, priority scan, and transmitter time-out timer in user program mode. However, it may not be necessary to change these functions after they are set. To simplify handling by the user and to prevent operation errors, it is also possible for the dealer to preset the user program when writing the assigned frequencies into ROM. In this case, the user cannot change the preset functions.

Figure 9 shows the operation and display parts of this radio; Figure 10 is the general flowchart.

4.5 Mechanical design

"User friendly" design is applied to mechanical design as well as to electronic circuits and software design.

The push-to-talk switch, which is used frequently, is attached at an appropriate angle so that it can be pressed easily when the radio is held in the hand.

To simplify operation, electronic controls are arranged on the upper part of the radio. With this arrangement, the controls can be freely operated either when the radio is held in the hand or when it is hanging at the waist using a belt clip.

A die-cast aluminum cabinet with an H-shaped inside section is used. (See Figure 11) This structure enables efficient heat radiation even for high transmitter output of 5 W and protects the internal electronic circuits. The wall in the middle of the

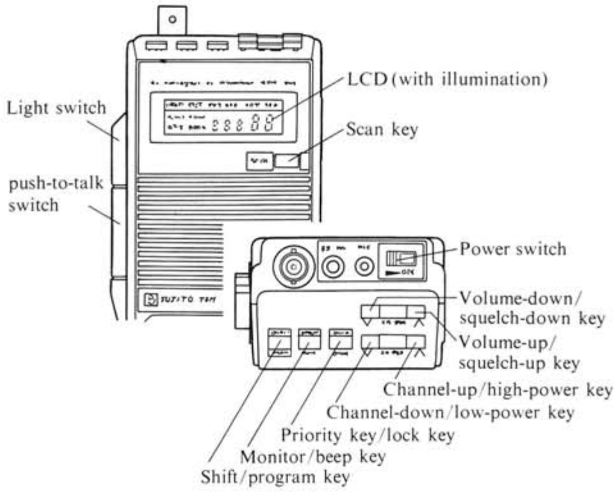

Figure 9. Control and display of FTP40-592H

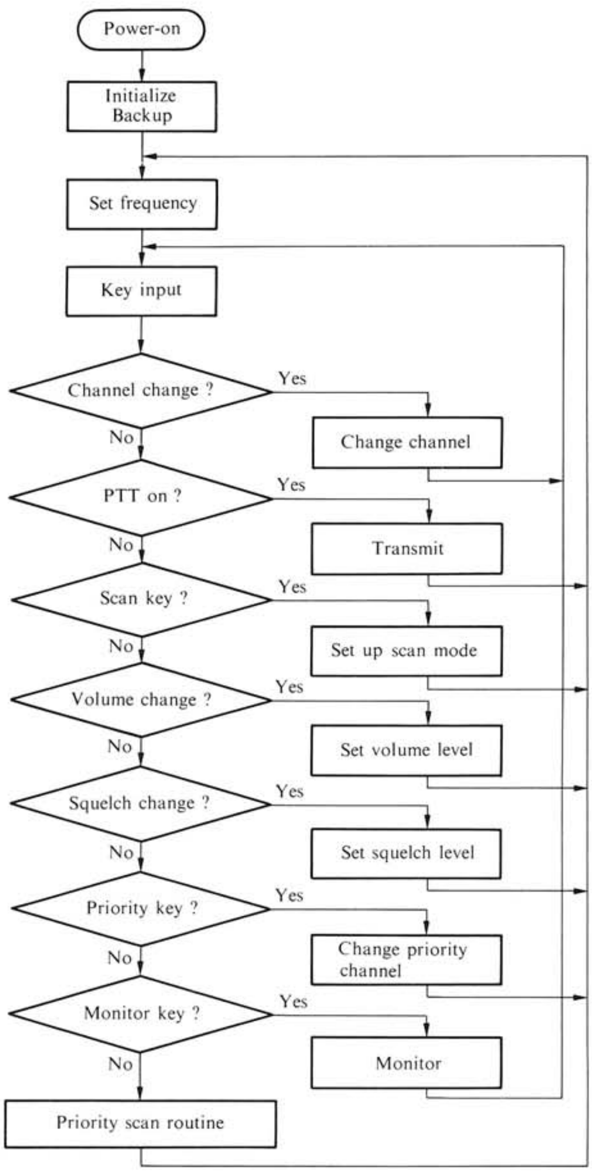

Figure 10. General flowchart

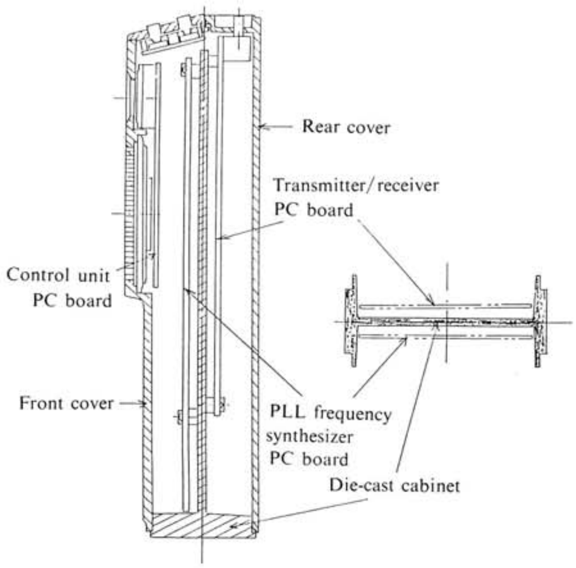

Figure 11. Structure of equipment

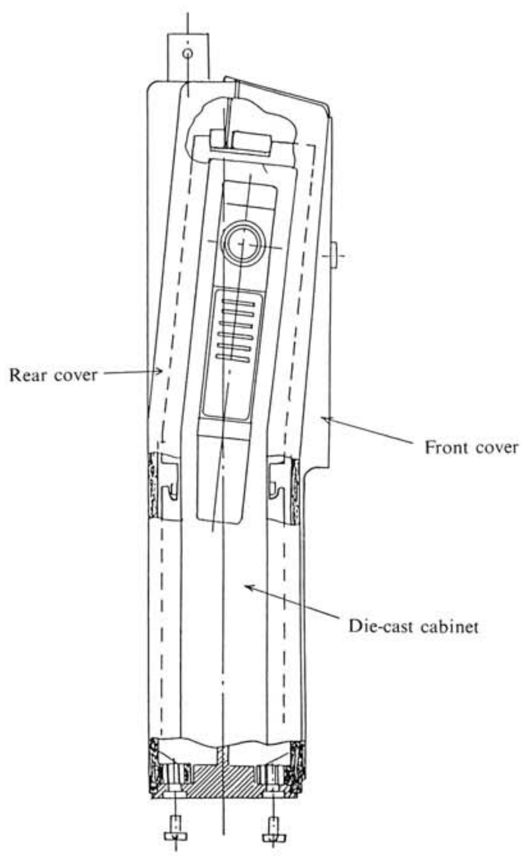

Figure 12. Assembly of covers

die-cast separates the transmitter/receiver PC board from the PLL frequency synthesizer PC board, thus eliminating mutual interference.

To improve the design, screws are not exposed outside the equipment. The front and rear covers hang on the die-cast cabinet at the top and middle and are fixed with screws on the battery-attachment surface at the bottom. (See Figure 12)

5. Conclusion

The preceding sections describe the features and key points of design of the newly developed FTP40-592H portable radio.

This development provides both mobile and portable 400-MHz band PLL frequency synthesizer radios for the U.S. We hope to continue the development of products satisfying users' needs, by adding new technologies to those obtained through the development of the FTP40-592H portable radio.

Reference

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